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SOIL CONSERVATION SERVICE AND E. C. W. ENGINEERS

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# GULLY CONTROL MEASURES OF THE SOUTHWEST

by
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The problem of gully control in the southwest demands consideration of several important factors that are not likely to be found in other parts of the United States. First, it is a semi-arid or arid region where rain seldom falls from March to the following December, and the watersheds are therefore lacking in sufficient native vegetation to serve as an effective control of the runoff; added to this is the resultant difficulty of establishing vegetative means of control that will survive the extended rainless period during the hot summer months. Sod, as it is known in other states, is practically non-existent, while recurring fires sweep the native vegetation from the watersheds, leaving them bare and free of all runoff-retarding brush or litter.

Second to be considered is the fact that, although our rainy season is short, and the intensity of our precipitation light in comparison with some other states, the sparsity of vegetation on the steep pitching watersheds, combined with the relatively short period of rain, causes flash flows of large quantities of water, which attain high velocities as they sweep down toward the ocean bearing heavy burdens of debris, and taxing all varriers to great limits.

Some idea of our conditions may be had from comparing the policies of erosion control in other parts of the country with ours. I have noticed in the monthly publications from other Projects that slopes ranging from 12% to 15% are being taken from cultivation, while out in our region bean farmers are producing crops every year on slopes of more than 60%. The same applies to gullies. These publications speak of controlling 2% gullies, but we would hardly consider a grade as low as that as needing control.

There is another factor of real importance that I will discuss at greater length later on, and that is the land values. A farmer owning twenty-five-hundred-dollar-an-acre land is not a very good sales prospect to approach with a proposal to devote three or four of his acres to grass or soil-holding plants in order to control a gully.

From the foregoing, you can see why the southwest must resort to mechanical means of gully control to a greater extent that in other sections. We do not maintain that this method is superior to natural means of control; on the contrary, we consider it our misfortune that vegetative methods have not proved adequate. I have read where you people in Wisconsin are controlling outlets on an 8% grade with sod, but our grasses must be reseeding annuals, and consequently our rains are upon us before we have any semblance of sod. Even the establish-

ment of vegetation usually calls for extensive mechanical control to prevent undercutting; therefore, the greater part of this paper will be largely confined to mechanical methods.

## STABILIZATION GRADE

In the designing of a system of checks for any gully, the first consideration in locating the dams is the grade at which neither cutting nor deposition will occur. Stabilization grades vary with the different types of soil, as we all know, and there is no formula to determine them. Our only recourse is to observe grades behind old existing dams and in ditches or gullies which are stabilized. Then we must guess at a factor of safety which will provide for the unknown factors of varying silt content and velocities and also protect the lower side of the structure until deposition from the dam below is completed. This is one of the phases of soil erosion control where experimental work should be done. In our Ventura Project, where the soils consist largely of loams and clay loams, grades which vary from 1% to 1-3/4% have been proved by experience to be correct. In the Arroyo Grande Sub-Project, which has a very sandy soil, grades of 3% to 4% are satisfactory; still again, in portions of the Corralites Project, where the sandy soil contains a large amount of iron, ditches up to 8% are not cutting, while grades below 5% are silting badly.

Stabilization is, of course, the objective of our gully control work at this time. In the southwest, a wide variety of structures are used, depending upon the permanency desired and the local materials available. Due to the scarcity of timber, logs, and even good brush, rock of some sort is used in a great percentage of the structures built.

## TYPES OF DAMS

In the Las Posas, we have used stream boulders in rock fill dams up to 15 feet in height, and in smaller checks as grouted retaining walls and as loosely laid riprapping. Flagstone is being used in small checks, aprons, and in paving spillways as well as in building sidewalls. We grout dams which have a hydrostatic head of four feet or more, and build them as an arched retaining wall. Smaller checks of flagstone rock are constructed, as described in the August number of the Navajo Project News, a wedge type dam developed on that project, which is both cheaply and easily built, and when provided with a suitable apron should become a permanent structure. Another type of dam, composed of rectangular rocks of even size and laid so as to form an arched stepped spillway with the rock laid on an upstream slope, also developed on the Navajo Project, has the advantage that any slippage will tend to wedge the rock more closely.

Rock and wire baskets, or sausages, are frequently used in the large gullies where boulders are available in large quantities. This type of dam is very efficient, provided tie wires are run from the lower mesh through the dam to hold the top mesh snugly in place. A variation of this type used on the Gila Project consists of vertical cylinders of wire mesh filled with rock as individual units and placed contig-

uously across the stream channel. They can be curved upstream in order to get the arched effect in the dam.

Post and wire dams, using 4 x 4 electric welded mesh No. 8 gage galvanized wire, are used in large numbers in the smaller gullies. In our Ventura Project we have no cheap wooden posts available, and so have resorted to posts made from junk iron pipe secured from the adjacent oil fields. They have several advantages, among which are that they will not burn, are easily installed, and, since they are driven in, are firmer than posts set in an excavation. Such structures have a life of fifteen years or more, and can be considered as permanent, whereas those using lighter wire are temporary. In order to prevent the desilted water from cutting out the brush or straw used in the dams, we now cover all wire with a layer of burlap that has been dipped in asphalt. This assures the retention of all silt, and confines the flow to the spillway.

In some cases where this type of dam was subjected to fairly heavy flows, and lifts of four feet or more were desirable, they have been built with a double row of pipe and wire set about 18 inches apart. Straw is packed between, and the two rows of pipe are securely anchored together. We have never had a single failure with this type of construction, although we have built them up to 8 feet in height.

In the matter of spillways, we have had better success from the depressed center type of dam than from the notched spillway. The former offers greater capacity and confines the flow more definitely. We have also found that the weakest point in this type of dam is the carelessness of the men who build them.

Another type of dam for larger gullies which owes its origin to the availability of suitable material in the Ventura Project, is the iron post and wire cable type. The posts are driven in a down-stream arc and the cable woven as tightly as possible between them. The ends are anchored to deadmen located in the banks, and, where deemed advisable, center posts are anchored to deadmen upstream. The cost of materials for this type of dam is low; however, they are heavy and consequently expensive to handle, and so far not many of them have been built.

In the Ventura Project we have a rather unusual gully control problem, in that gullies 60 feet deep traverse land valued at $2,000 per acre. These gullies are cutting deeper and wider, and some form of control is necessary. In this case it was considered economically justifiable to go into an absolutely permanent type of structure, to the end of stopping further cutting. A limited number of these larger dams were built, none over 20 feet in height, some of concrete, some of rock fill with spillways over the dam, and several earth-fill dams with spillways cut through the solid earth around the dam. The concrete dams were vertical drop, the rock fills were built with an "ogee" type of spillway, and the spillways for the earth-fill dams were concrete or rubble lined flumes. These earth dams were used only on sharp bends where the length of the excavation for the spillway was not excessive and where channel straightening was also desirable.

An interesting development in the Gila Project which is especially suitable to locations where both rock and water are hard to secure, is a type of dam built of sacks filled with a dry, lean concrete mixture, and then sprinkled, when water is available, or left to be wetted by the first rains. Sacks filled with earth and then dipped or sprayed with asphalt provide only a temporary type of construction, for our experience on the Ventura Project has shown that there will always be a few sacks which will rot out and cause the failure of the complete structure. Under less humid conditions, however, this fault may not exist.

Another method of gully control applicable to gently sloping grazing land is rather extensively used on the Navajo Project. The entire flow from small gullies is diverted onto fields and spread by means of staggered pervious dykes, usually constructed of wire and brush or burlap. Range grass has shown a decidedly increased growth as a result of this method of treatment.

## MEANDERING

Having stabilized the grade of a gully, all of us are then confronted with the problem of stopping meandering. We are making our greatest use of vegetation in overcoming this type of erosion. Drought-resistant trees such as willows, eucalyptus, black locust, Arizona ash, and the native shrubs holly and sumac, are planted along the bottom in dense masses to help confine the channel. In cases where protection is needed to start this vegetation, or the stream is sharply impinging against the bank, revetments or levees of post and wire have been used. Until this vegetative growth has become well established, considerable maintenance will be required; however, eventually it should provide complete and permanent control so long as free from damage by fires. With the grade established and the channel controlled, it will be only a matter of time until the sluff from the banks will assume a slope which native vegetation will stabilize.

## LATERAL GULLYING

The prevention and control of lateral fingers in deep gullies offers one of our most vexing problems. Runoff must be delivered to its drainage channel, but obviously it cannot be dropped 30 to 60 feet over vertical banks without causing trouble and consequently control structures that are efficient are rather expensive. Overfalls offer only temporary control, and are only used where other methods are impractical. On overfalls we recommend as much overhang as possible, and a slope of 1-1/2 to 1 on the conduit, the object being to prevent scouring at the toe of the bank. Lined ditches or conduits extending to the bottom of the gully are much to be preferred as a means of conveying the water, and when constructed with ample capacity, provide permanent control for lateral waterways. Diversion ditches and dikes are used to concentrate the flow in as few outlets as possible.

One troublesome source of danger is the rodents which exist in large numbers in our region. Their burrows are frequently the cause of lateral gullying, and we have found it a good investment to employ a man steadily to trap and poison ground squirrels, gophers and moles.

## IN SUMMATION

In conclusion, there are two phases of our problem that I feel are of sufficient importance to emphasize briefly; the natural handicaps that we have to overcome in the way of drouth, lack of vegetation, and velocity of the streams, and the high values placed on portions of the land where we operate. Orange and avocado land frequently reaches a value of $2500 per acre, and men farming unirrigated bean land often receive $100 per acre per year from their crops. These high land values and high crop returns force the farmer to see everything else as subordinate to the largest crop yield possible, and that attitude in turn frequently compels us to use permanent mechanical structures rather than attempt vegetative control that would take land from cultivation. These farmers had far rather spend large sums for dams than have trees, shrubs, or any moisture-sapping vegetation, which would also harbor rodents, along the gullies which crease their fields. So strongly do they feel in this respect that many of them have built dams themselves costing from $5,000 to $20,000.

We must also be guided in our decisions on the size and permanence of dams by the difference in cost of the large structures as compared to a number of smaller ones, the replacement cost, and the damage that might be incurred by failure of a structure. It is obvious that a considerable expenditure would be justified to protect a single acre of land worth $2500, and equally as obvious that the man who owns the land is going to object to the construction of any cheap structure which might subject his land to the risk of damage. Consequently, the type of construction must be guided by economic justification of the expenditure.

If $2 per acre for protection is justified on $20 an acre land, then by the same logic it is justifiable to spend $200 an acre to protect $2000 land, although actually our costs will average about $5 per acre. The modern, wide-awake farmer is just as aware of this economic consideration as you and I are, and we have found that in California we cannot gain his confidence and cooperation by any other reasoning. The value of control work must ultimately be figured in dollars and cents, not in acres or in dams. A survey of our problems in the southwest will reveal a high return per dollar invested, even though the handicaps are such that methods used generally over the country would be little short of money thrown away if applied under the conditions imposed by nature and extreme land values that are found in portions of this southwestern section.

# GULLY CONTROL AS RELATED TO THE ILLINOIS PROJECT AND THE MIDDLE WEST

by

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There was a time when most of the farmers in the United States could say that there was not a ditch on their entire farm that could not be farmed over. However, with the gullies that can be found on many of these farms today, this picture is now but a remembrance of the past. Such gullies have already ruined millions of acres of fertile farming land in the United States and are exacting an increasingly heavy toll.

Gullies in most areas present a wide range in character, from small hillside gullies on the one extreme to deep cutting gullies on the other. Many of the latter have already reached the stage where their control may no longer be considered a conservation project. However, the heads and laterals of many of these large gullies deserve attention since they have not become stabilized, and there is still much further damage to result from the severe head erosion and waterfall cutting which is certain to continue.

## Value Of A Comprehensive Program

Gully control work when properly carried out may be divided into three phases: first, the building of suitable structures: second, the plowing in of the gully when the seasonal conditions permit; and third, the re-vegetation, which consists of seeding grasses and legumes or tree planting of the gully. Successful gully control can be attained only through a comprehensive program which includes all of these phases, thus involving the Agronomist, the Engineer and the Forester. No one group of these trained men working singly and without applying some of the practices of the other two groups can most successfully meet the problems of gully control. It is a place for a comprehensive and unified program rather than for a specialized and exclusive program.

## Classic Examples of Gully Erosion

It is interesting to study the origin and growth of gullies of known history. In most instances, their formation may be attributed to careless cultural methods, and certainly in light of our present knowledge their development and advance might easily have been checked.

In the Illinois Area, one of the cooperators rather apologetically tells the story of how the enormous gully now extending from corner to corner of his fertile section of land had its beginning from a plow furrow which was made by his father for purposes of drainage. Today that gully is one and one-quarter miles long. Since its formation, 823,750 cubic feet, or 37,000 tons of soil have been moved. This amount is equivalent to seven inches of soil over a 37 acre field. Certainly the results would have been quite different had some inexpensive dams been used

in this gully early in its formation. In addition to the enormous removal of fertile soil, I need only mention the way in which this gully has interfered with farming operations, marred the beauty and lowered the market value of the farm.

Further down the same major watershed, another cooperator has been considerably disturbed by the way in which his only good fertile bottom land has been covered by deposits of infertile subsoil material from the eroded hillsides above. In many places these deposits of glacial till have reached a depth of 30 inches.

I am glad to say that both of the above cooperators have benefited by the work of the Soil Erosion Service. In the former case, structures were placed in the gully so as to spread the flow and check further active cutting. Later the banks are to be sloped and seeded so as to form a grass waterway. In the latter case, an earth dam and a brush revetment have been placed along the stream so as to preventthe water from flooding over this fertile bottom and depositing its load thereon. In addition to this, tree planting and grass-legume seeding has been started on the erosive slopes which have been furnishing the unwelcome subsoil.

Nearly two years ago, an 84 year old farmer of North Missouri took me out to study what he considered his most baffling problem in all his years of farming. A huge gully had formed during the past ten years, in what was supposed to be an over-grazed pasture, but which in reality was only a gymnasium for his live stock. One lateral of this gully, which was fifteen feet deep, had encroached to the side of the road, much to the alarm of the road officials. Another lateral was fast encroaching on his farmstead. Many other laterals were eating their way back through his productive fields.

## Gullies Affect Evaluation

Nor is the farmer alone in his recognition of the importance of gully control. Not long ago a prominent citizen, and owner of a good corn belt farm in Central Illinois, related the story of how one of the Federal Land Banks had rejected his application for a loan because of the serious and increasing erosion in the gullies on his farm. However, the appraiser for the Federal Land Bank promised quick action as soon as the farmer would control the destructive gullies. Through studying the work of the Soil Erosion Service and with a few suggestions on the part of an Engineer, this farmer has been able to effectively control his gullies at a low cost and thus satisfy the demands of the appraiser.

## Gully Erosion As Affecting Roads

There is another agency which of necessity has become vitally interested in gully control. I refer to the road officials of our various units of government.

Not many months ago, I observed a classic example of very destructive and dangerous erosion along a township road in what is considered a flat section of Central Illinois. In 1912, just twenty-two years ago, the

road commissioner of this township ran a plow furrow along the side of the road in an effort to secure proper drainage. Today that drainage ditch is three-quarters of a mile in length and is still growing. At a distance of one-quarter of a mile from its mouth, actual measurement showed it to be 100 feet wide and 35 feet deep. In fact, an entire freight train could pass down this gully only to be seen by the rising smoke of the engine. In spite of various expensive structures that have been built to check its advance, it is still eating its way back through the deep fertile soil without respect to either field or owner.

A cooperator of the Illinois Area recently threatened suit against the County Highway Engineer of his county because a road culvert had concentrated the water to the extent that it was eating a gully through the best pasture on his farm. The county officials could do no more than acknowledge their mistake and construct corrective measures.

In a program which was primarily launched for beautification of highways, our State and Federal Road Officials have also done admirably toward preventing unsightly and dangerous road-side ditches along the paved highways. However, there is still much to be done in the way of constructing drop inlets to existing road culverts and encouraging other such practices.

## A Coordinated Program

Since the importance of gully control practices has been discussed, let us now turn to what may be considered the basic principles of gully control, and the relationships of gully control activities to the other phases of a well rounded, coordinated erosion control program.

### Engineering

In considering the Engineering aspects, it would seem desirable that the best possible structures be constructed at the lowest possible cost. In other words, the matter of gully control work by the Soil Erosion Service should be a practical demonstration of such a nature that it could be carried out by the farmer himself. For the most part, this means a minimum of cash expenditure and, insofar as possible, the use of such materials as are available on the farm.

The use of good engineering principles in the design and construction of the structures is very important. This means that the weir notch should allow for the maximum spread of flow and should be of sufficient size so as to care for the maximum anticipated run-off. The foundation of the structure should extend far enough below the bottom of the gully and into the banks so as to avoid the possibility of water being forced under or around and thereby undermining the structure. The structure interval must be considered and suitable aprons should be provided.

Then too, it is necessary that the Engineer should so design temporary structures as to care for the situation of the future. In other words, just what is going to happen when that structure is no longer effective? In a great many cases that I have observed, it appeared that waterfall

cutting, and the removal of whatever fill has accumulated is certain to follow at the time that the structure has rotted away. Such situations could have been avoided had the apron been so constructed that a flume effect would have been obtained, thus avoiding waterfall cutting.

## Agronomy

For the most effective control of gullies, in any area, there must be some consideration as to Agronomy - including both soils and crops.

Perhaps the subject of soils may be briefly covered by way of an illustration drawn from the Illinois Area.

The Miami silt loam is a timberland soil, and occurs over much of the rougher portion of the Illinois Area - those areas requiring much gully control work. Because of the low organic matter, the voids (or pores) of the dams in this type of soil must be much smaller than in the dams of most of the other soils of the area, in order to prevent silt from escaping. Lack of available plant food in this type of soil also makes it much more difficult to secure a dense growth of vegetation.

Then too, bank erosion (small gullies down the slope of a gully bank) is much more common on the Miami than on the prairie soils. In order to prevent this excessive bank erosion, much more attention must be given to the providing of brush and straw mulches over the raw banks.

Due to the more compact B horizon of the Miami, as compared to the prairie soils, greater care must be used in getting the base of the structure well embedded in the bottom and sides of the channel.

Still another problem soil type encountered in the Illinois Area is the Elliott. Here the problems arise as a result of the impervious subsoil which so often is found near the surface. Because of the hard digging in such a sub-soil, often the structures are not embedded deeply enough. Then too, due to this impervious subsoil, the water which is ponded on the upstream side of the structures does not allow for the good growth of vegetation.

A great many gullies may be entirely checked by re-vegetation alone. Where such method of control is possible, it should be practiced as it will expedite the work as well as prove to be less costly. Then too, since most of the structures built by the Soil Erosion Service are rather temporary, vegetation is a rather important factor.

For the most effective gully control, considerable thought must be given to the matter of decreasing the run-off. Certainly lessening the amount of water which runs down a given gully will assist materially in any structure and seeding work for control, which may be undertaken. Again, herein lies the value of a close correlation of gully control activities with the work of the Agronomist. Perhaps the value of crops in this connection can be made no clearer than by way of reference to the experiments conducted by the Missouri College of Agriculture. Here it was found that over a 14-year period the run-off varied from 12 percent of the rainfall for the bluegrass sod to 30.7 percent for the land plow-

ed 4 inches deep and kept in cultivated fallow. The run-off from continuous corn land was 29.4 percent, from continuous wheat land 23.3 percent and that from a rotation of corn - wheat - clover was 13.8 percent, or only slightly more than from the sod.

In most Soil Erosion Areas in the middle west considerable attention is now being given to the matter of grass waterways. Usually there is a feeling on the part of the farmer that such waterways take productive land away from cultivation, or that it is too much bother to raise the plow in crossing the waterways. As to the former argument, I would like to direct your attention to the observation of one of the commercial Farm Management men of Illinois. This man considers such waterways to be an asset from the standpoint of lessening the amount of poisoning where stock are allowed to pasture the corn stalks during the winter months. In addition to this a certain amount of desirable roughage is furnished.

Relative to the trouble caused in lifting the plow when crossing the waterways. It must be admitted that there is some inconvenience in such a practice, yet it is true that continued gully erosion resulting in separate fields, made necessary by gullies which cannot be crossed by farm machinery, is an even greater inconvenience.

## Tree Planting For Gully Control

As has been previously stated, tree planting in gully control represents one choice of vegetation. For the most part, trees should be used in those gullies that are large and difficult to control. They have an important place in the gully control work, and their use in the rougher areas should be highly recommended. Trees should usually be planted in gullies that occur in pastures, at one end or in an out of the way place in a cultivated field or in areas that are to be retired from cultivation.

A prominent farmer in Southern Illinois proudly points to 45 acres of Black Locust trees as his most profitable cash crop. According to this owner, 35 years ago this area was so badly eroded and gullied that he was forced to abandon it from crop farming, and in despair he planted it to Black Locust. Since that time he has but three crops of post which he has traded to the neighbors for an amount of corn which has been produced on a considerably greater acreage. He further explains that this area produces practically as much pasture (orchard grass and Blue grass) for his livestock as do those pasture areas not having trees.

## Terracing

Gully control is so closely related to terracing, that we can hardly have a discussion of either of them separately. Many small hillside gullies may be entirely controlled by terracing. Then too, natural drainage channels should be used as outlets for terraces rather than artificial channels whenever it is possible to do so. Observations in Illinois, to date, indicate that such outlets lessen the total cost of caring for most watersheds.

## Records

If the gully control work of the Soil Erosion Service is to be effective, all parts of the program must be carefully planned and systematically carried out. Before the work on any gully is started, a very definite plan of control measures of that given situation must be worked out. Furthermore, since this represents a huge demonstration, it is valuable that a record be kept of all the work done on the gullies. By keeping complete and definite records we may soon be able to prefix more of our statements by "we know" rather than "we think".

## A Practical Demonstration

As has been previously mentioned, it would seem that these Demonstration Projects should be made as practical as possible. In so doing, it will be possible for the work to find wider application than the area boundaries as now established.

Just this last summer, one of the good Commercial Farm Managers of Illinois contracted with two men to build wire check dams on several of the farms under his supervision. The contract provided for the building of wire check dams approximately two rods in length at a labor charge of $2.10 per dam - the post and wire to be furnished by the owner. By spending a day in the area and working with the gully control crews of the Soil Erosion Service, these men were able to build satisfactory wire check dams on farms in other parts of the state.

## Gully Prevention

Gully prevention measures also include measures which aid in checking the gullies which have already formed. It must be remembered that gullies form more rapidly than they can be effectively controlled under careless farming practices. Therefore, in conclusion it would seem well to list such preventive measures as follows:-

A. Approved methods of farming which increases the absorptive capacity of the soil and lessen the run-off. The use of barn-yard manure, application of commercial fertilizer or lime, crop rotations, the use of sod crops and contour stripping are valuable in this connection.

B. Conducting the surface water from the field at a low velocity such as is done in terracing.

Mechanical structures will help solve erosion problems only as the farmer is taught to adapt his farming practices to avoid serious sheet and gully erosion. Temporary structures are only a means to an end and that end is re-vegetation.

## Illustrations

The following slides illustrate structure types and adaptations in use in the Illinois Area:-

| Code | Kind Of Picture |
|---|---|
| 660 | Wire Check Dam |
| 241 | Wire Basket Net Dam |
| 237 | Staked Low Center Brush Dam |
| 246 | Two Post Brush Dam |
| 238 | Multiple Post Dam |
| 618 | Log Dam |
| 242 | Loose Rock Dam |
| 656 | Sod Bag Dam |
| 387 | Earth Dam with Side Spillway |
| 706 | Drop Inlet To Existing Road Culvert |
| D-4-31 | Diversion Terrace |
| 197 | Willow Revetment |
| 431 | Preliminary Survey |
| 433 | Daily Work Report |
| 434 | Structure Specification Tag |
| 429 | Completion Report Of Gully Control |
| 436 | Individual Farm Summary Of Gully Control |
| 307 | Tile Outlet |
| 315 | Road Flume To Terrace Outlet |

# GULLY CONTROL IN THE SOUTHEAST

by

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Of all forms of general surface erosion gullying characterized by downcutting, accompanied by undercutting and caving, is most rapid in its progress and most difficult to check. It is likewise most spectacular in its appearance and most destructive in its effect. Gullying, is the result of the concentration of run-off water in depressions on slopes, the velocity of the water having been sufficient to overcome the resistance offered by the soil and its vegetative cover. From a study of aerial photographs and ground surveys made by Soils Experts and Engineers of the U. S. Soil Conservation Service on the South Tyger River area in Greenville and Spartanburg Counties, South Carolina, it was found that approximately 1500 gullies having a depth of eight feet or more existed. This is in a watershed area of approximately 120,000 acres. Some of these gullies have assumed enormous proportions. There are a number having a depth of as much as fifty feet and width of over 100 feet. In almost every instance their sides are vertical.

No record has been found of where a scientific study has been made which would explain the formation of these gullies; however, some interesting observations have been made by a number of Soil Specialists and Engineers in an effort to devise control methods. It is interesting to note in this connection some of the soil and topographic conditions of this area. The South Tyger River rises on the Eastern Slope of the Blue Ridge Mountains only a short distance from the state line between North and South Carolina and flows in a southeasterly direction some 40 miles, where it joins the North Tyger in forming the Tyger River, and the highest known elevation is 1528.9 feet above sea level. The lowest known is 573.6 feet. In this distance of 40 miles there is a net difference in elevation of 955.3 feet. Comparing this with the Mississippi River, which at a point near Cairo, Illinois is less than 500 feet above sea level, in approximately 900 miles from its mouth we can imagine the force and eroding power such a stream as the South Tyger will have under flood conditions.

In a study made of the soil and vegetative cover of the watershed area, it was found that approximately 40 percent was covered by forests or small wooded areas and 60 percent in open land, the majority of which is in cultivation. Soil types have been mapped over the entire area and the Cecil series predominates. Some of the lands in the area have been in almost continuous cultivation for over 125 years. About 20 percent of the area is largely abandoned, due to excessive erosion.

The gullies are fairly well distributed, though the majority of them appear in the lower end of the area where the lands have been in cultivation over a longer period of years. 3 percent of the open land has a slope of 3 percent, or less. Naturally, very few gullies exist on

these slopes. 40 percent of the open land has a slope of from 3 to 7 percent, and 42 percent from 7 to 12 percent. 13 percent has a slope greater than 12 percent. Much of this land above 12 percent is in cultivation and planting to trees or permanent pastures. Since 97 percent of the open land in the area has a slope greater than 3 percent and has been in cultivation for such a long period, during which time cotton and corn have been the principal crops grown, sheet erosion has been most extensive. In fact, surveys made by soils men which are not entirely complete at this date, indicate that approximately 40 percent of the open land has lost more than 80 percent of its topsoil. This condition has exposed the hard, red subsoil and gives a characteristic red color to the entire landscape. This hard, red clay subsoil is high in colloid content and very dense, which makes it resistent to erosion. At the same time, when so much of the surface soil has been sheet-eroded and the clay left exposed and undisturbed, the runoff from heavy rainfalls is very rapid and approaches approximately 90 percent.

Terracing, which is about the only erosion control method that has been employed, has been a well-established farm practice for the past fifty years. It requires only a casual glance, however, at aerial photographs and fields to see that these terraces have been inadequate to bring about effective control. They have been built on fields with practically no coordinated system of water control from ends of terraces to a stabilized gradient. In nearly all instances very little regularity exists as to vertical interval, uniformity of grade and capacity of water channel. The terraces have been built by farmers with their existing power and equipment, which largely consisted of a two-mule plow. Lacking skill in planning the terracing system and running grade lines, as well as adequate equipment for construction, the farmer has no doubt done the best he could under the circumstances.

It is easy to understand that under these conditions terraces would break during periods of excessive rainfall, and since they serve to concentrate water, considerable quantities would be directed through these breaks. Broken terraces, therefore, have constituted one of the principal causes of gully formation. The matter of disposal of the water at the ends of terraces has also been sadly neglected. The farms in the area are relatively small and land lines are frequent. When terracing a field, the idea has been to get the water off the field and in quite a large number of cases, adjoining farmers have agreed to plow a ditch down the slope on the land line to act as a terrace outlet channel. It can therefore be stated that line ditches are the second most important cause of gullies. Where line ditches were not employed, the terraces were run to existing roads and the water emptied into road ditches. Since these roads were constructed by the Counties of Township units, very little attention was paid to them in regard to erosion. The result has been that road ditches have become so deep and the roads so narrow that it was often dangerous for travel. The usual remedy for this condition was to move the road to a new location, usually just on the side of the old right-of-way, in which case the abandoned road became a gully.

The nature of the soil horizons has given rise to a rather peculiar growth of gullies. As soon as the topsoil or "A" horizon is removed by

sheet erosion, the hard clay subsoil, previously referred to and known as the "B" horizon, is exposed. Since this "B" horizon is resistant to erosion, progress, in the formation of large gullies, is slow until the strata is cut through. As long as the gully is in the "B" horizon it is characterized by a channel, whose depth is sometimes as much as four times its width. Underlying the "B" horizon is the parent material of the soil and is known as the "C" horizon. In the South Tyger River watershed area this "C" horizon has characteristics that are greatly different from the "B". It is relatively soft, micaceous subsoil composed of disintegrated granitic rocks. This "C" horizon material has the outward appearance of granite rock, but is completely disintegrated and is quite soft and very incoherent when pulverized. It presents our most serious problem in gully control, since it has no stability for structures and is devoid of organic matter, plant food, or bacterial life, all of which are necessary for plant growth.

When a gully cuts through the "B" horizon into the "C" its development becomes very rapid. Observations have been made in which gullies have progressed as much as 50 feet after a 1-1/2 inch rain. A gully grows from the lower extremity upward and develops an ampitheater shaped head in which caving plays a prominent part. In a single rain as much as 1000 cubic yards of earth have been known to cave. Over a period of years it will develop into chasm-like proportions and eat its way even into forested areas. making it most difficult to check without very expensive treatment. Since the "B" horizon is usually around 4 to 8 feet thick in the South Tyger River area, gullies that are passing from the "B" to "C" stages have a high vertical drop at the head of the "C" horizon. If the gully is to continue to carry run-off water and be treated as a controlled waterway this eating head with its high vertical drop and unstabled base becomes the most critical point of control.

In its program of setting up watershed demonstrations, the Soil Conservation Service on Project number 5 is committed to vegetative control measures. This would seem most logical on such an extensive area and under the soil and topographic conditions that exist. Vegetative control is also basically sound. There are two very great handicaps, however, in making it completely effective. First is the large amount of topsoil that has been lost by sheet erosion and over the gullied areas. It is almost impossible to get any natural vegetative cover where soil conditions are not favorable for its growth. Both the surface soil conditions surrounding the gully and the nature of the soil in the "C" horizon which constitutes the bottom and much of the sides of the larger gullies make vegetative control measures practically impossible without considerable alteration of these conditions. The second handicap to vegetative control is the background of the farm people who live on and farm the area. Land in the watershed is privately-owned and the Government enters into a cooperative agreement in which the land-owner agrees to do certain things along with the Soil Conservation Service in carrying out the erosion control methods. Bermuda grass is considered to be the most erosion-resisting plant that grows naturally in the area. It is well-established in some sections but is looked upon by practically all farmers as a pest and an enemy. For generations farmers have fought grass, weeds and every type of vegetation in producing clean cultivated crops such as cotton or corn. Most of this fight has been in the form of chopping the grass and weeds from the cotton and corn plants by hand. It is but natural that people who have had to expend muscular

energy in doing this over a long period of years would be very antagonistic to its reinstatement, even in gullies and terrace outlet ditches.

In the foregoing, an effort has been made to present a picture of the situation that exists in the South Tyger River area in order that the gully control methods which have been employed during the past year might be better understood and appreciated. The first gully control work on the area was begun during December 1933. For a period of six months, relief labor under the CWA and Transient Bureau were used for the work. At the beginning, quite a large number of men had to be put to work in a very short time with little equipment and without trained supervision. Naturally many mistakes were made and costs of treatment were excessive. With no basic data on which to plan control measures more or less conventional types of structures were employed. A few large gullies at the beginning were treated as waterways in which log dams were used, placed on the "C" material. Plank flumes, or drops, were used at the head to conduct the run-off water into the deeper portion and check the eating head. Only a few excessive rains in the spring were necessary to show that this means of control was unsatisfactory. In many instances the log dams were 4 and 5 feet high and were consequently washed under. The drops or flumes were also ineffective because of the difficulty in anchoring them in the "C" material. Hand sloping of the vertical banks and the head, preparatory to planting, was considered too expensive since the hard "B" strata was so difficult to move by hand methods. Low grade dynamite was used at a later date to effect sloping, but it was also found to be expensive and that some time was required for the banks to settle sufficiently for planting. This method is, however, still being used in some instances where the depth is excessive.

Some brush dams were used along with logs, but the labor and cost of procuring same caused their abandonment.

Wire dams are now being used as a temporary structure, placed vertically so that their height does not exceed 18 inches. Heavy guage one and two-inch mesh poultry wire was used for this purpose and a strip of burlap placed behind same to hold the "C" material until vegetative cover could be established. A 1x3 creosoted board is used along the top of this dam to support the wire between posts and give the dam a distinct notch or spreader board effect. These dams have been reasonably successful in controlling conditions found in the bottom of the large gullies and where it is possible to place Bermuda grass back of these dams, control is effected in a comparatively short time. Where a large amount of loose earth has been pushed into the gully on the sides and head, these dams are not very stable until complete settlement has taken place and constitute a danger point that requires attention and frequent repair.

Permanent structures such as loose rock wire, rock masonry or concrete were not considered practical because of costs and lack of suitable foundation for such structures when treatment in the "C" horizon was involved. These structures, however, have proved successful and practical when placed in a gully whose floor is still in the "B" horizon.

With the substitution of CC Camp labor for other forms of relief labor, more definite plans of gully control were made. It was realized that much experimental and costly work would have to be done before a satisfactory system of control could be effected. A small hydraulic laboratory for testing various structures was instituted and a Hydraulic Engineer was employed to conduct tests on same. This work was most beneficial and resulted in the working out of certain designs and tables that appear to be giving satisfaction. In working out these, our Engineers made close contact with the erosion Experiment Station at Statesville, North Carolina. In fact, all available data that was applicable was used. A definite type of apron was worked out for both structures with low heights and flumes, or gully drops, as we call them. This design was such that turbulence was reduced to a minimum with a maximum energy dissipation. Pressure-treated creosoted timber was used in a large number of structures but was not found to be entirely satisfactory. This material is promising for use as flumes or gully drops, and is also being used for spreader boards in treated waterways.

Since it became apparent that even with most any type of structure the treatment of large gullies, which would continue to carry runoff water, would be excessive, a plan of diverting this water was instituted in an effort to reduce costs. Since so many gullies had formed from line ditches it was not always possible to divert water from the head. Where this could be done and ditches, as well as structures, kept in the "B" horizon, the problem of control was greatly simplified and costs reduced. The policy now is to use this type of control wherever possible. A diversion ditch is constructed around the head of the gully and the water at the end of the diversion ditch conducted into a wooded area or down a slope that is still in the "B" horizon. A 50 horsepower track-type tractor equipped with trailbuilder was also secured for use in sloping gully banks. This method has been most satisfactory and economical. Unless gullies are very large, the sides and head are pushed in and planted to grasses and trees without the use of any structures. Where such gullies are not too deep and if soil is sufficient to support vegetation, the cost of sloping the banks and planting same may be eliminated to reduce the cost. It would, of course, take much longer time to stabilize a gully with vegetation by this method.

Before any gully work is attempted, a reconnaissance survey is made and plans drawn for the control system. Watershed areas are determined and type of structures and treatment designed. A complete record is kept of all work and the resulting costs are complete in every detail. For example, camp labor is charged at the prevailing PWA rate of 40¢ per hour. Supervision, engineering, transportation, materials, etc. are also included. These are all broken down as such on the record which permits a complete analysis of costs. These records reveal a very high per-acre cost when balanced against the watershed area and persons who are unacquainted with the details and procedure often become alarmed at what they consider excessive costs. It happens that the South Tyger River watershed runs across something over one-third of what is known as the Piedmont Area of the Southeast. It is greatly favored in both climate and rainfall, having a 50-inch annual average over a period of 57 years. The area is also largely industrialized with numerous cotton mills and other manufacturing enterprises. It has been looked upon as a most favored section for the decentralization of

industry. While some 20 percent of the area is considered worthless for agricultural purposes, the majority of the land is still considered valuable and is rather thickly populated from a rural standpoint. A large number of farm homes have electrical services from rural lines. The average value of the land in cultivation is considered to be around forty dollars per acre. Considering that gullies are a most serious menace, not only destroying the land they occupy but making bottom lands below unfit for use because of the discharge of "C" material, the per-acre cost required for treatment and under the conditions encountered during the first year of work are not thought of as being unusually excessive. We feel that these costs will continue to be reduced and at the same time more effective control measures instituted. To date, 154 gullies have been treated and are considered to be under control. That the farmers in the area appreciate the value in protecting their land from the ravages of erosion, we quote from the Greenville, South Carolina Piedmont of January 22, 1935 the following statement made by one of the farmers in the area:

"My farm does not look the same. It is impossible to estimate the worth of this work, but I consider the value of my farm has been increased fifty percent by the improvements done by the Soil Conservation Service."

# TERRACING IN THE SOUTH

by

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TERRACING IN THE SOUTH - The very foundation for a soil conservation program where agricultural crops are being grown is a well planned, properly constructed and maintained system of terraces supported by a well balanced cropping system, including a maximum of close growing crops with contour cultivation.

A book might easily be written on the history of terracing in the south. The earlier development of terracing in this country had its inception in the south and mainly in the southeastern states. Unrecorded history passed down by our older settlers dates the beginning of terracing in this section back over 100 years. At the present time we find old terrace lines in areas long abandoned and now grown up with timber, some of the trees according to our foresters being 75 to 80 years old.

With these earlier terraces just about every man who started them varied the idea sufficiently to make it original. Some of us can easily recall reciting from our earlier texts the various type terraces, their design, and special conditions for which they were suited. With practically all of these earlier terraces there was a very narrow ridge, except for the bench type which developed into a succession of steps, and a fall of one foot to two feet and more along the channel.

The biggest single stride in the development of terracing was started by Priestly Mangum on his farm at Wake Forest, N. C., in the latter part of the last century, when he conceived the idea of a broad base terrace with sufficient fall to carry the water off and with the ridge sufficiently wide and flat that it might be cultivated. Mr. Mangum died about 1907 and the work on the old place has not been maintained, but throughout the south and over the entire country now we are using this same broad base or mangum terrace with the refinements that have been developed since that time. These refinements have been mainly in the form of grade cross section, width of channel and spacing.

The extension service in the various states has done much to extend the use of terraces in the protection of land from erosion, and the ten soil erosion stations located in various states over the country have made a notable contribution in developing the finer points such as grades, spacing, length, cross section and width of channels.

At the present time there are just about as many different systems or outlines being followed in the design of terracing systems as there are groups heading this type of work and yet there is so little difference that about the only impression we get is that one group is doing a better job of constructing terraces or taking care of outlets than the other.

In reviewing the development of terraces up to the present time there are two things that should impress us most, in fact that should stand out as red flags in connection with our terracing programs. (1) Proper consideration has never been given the protection of outlets, and (2) For the information we have had our plans have been good, but our results in the field have too often failed to come up to the specifications. Of course, we have said that it was the farmers' job to take care of outlets and make fills, but the reaction has been against terraces when a terrace outlet develops into a gully or when breaks in the terrace line started new gullies in the field.

We refer to our work in the North Carolina area as a complete, well-rounded farm program that is being executed in the form of a concentrated extension program that will mean most to the individual farmer in holding and building up his land, by use of the very best methods and cropping systems that have been developed up to this time. Of course, the engineering group feels that it has the biggest job and they are encouraged to do so just as every other group should if they are to make the most of their jobs.

Our work is the most visible at all times and certainly if we get a failure it isn't overlooked, while a few trees may die, grass fail to sprout or grow, it is soon forgotten.

Results of experiments on the soil erosion station at Guthrie, Oklahoma indicate that over a period of two years there was an average loss of 66 tons of soil per acre on unterraced land, while the average was 2.65 tons per acre for a terraced area similarly cropped. The top six inches are the most valuable from the standpoint of crop production. As the surface soil is permitted to wash away, crop yields are reduced. From the above figures it can be seen that it is possible to lose the entire productive surface soil in from fifteen to twenty years.

With the usual practices followed in growing cotton, tobacco, corn, and other row crops, from 25 to 50 tons per acre of soil may be lost each year. In North Carolina 87% of our erosion occurs during the months of June, July, August and September. The average annual rainfall in this section is approximately 50 inches. The major portion of the rain falls during these four summer months when the soil in the clean cultivated row crops is exposed and most susceptible to erosion. Terraces, when properly constructed and maintained, not only serve to keep the soil on the farm, but assist in conserving moisture which is a controlling factor in many sections in the production of farm crops.

Recent experiments with terraces constructed on various grades have given the results indicated in the table below:

| Fall in inches per 100 feet. | Loss of soil per acre each yr. |
|---|---|
| Level (with ends open) | 2.6 tons |
| 2" | 4.6 " |
| 4" | 5.3 " |
| 6" | 10.3 " |

Any terrace with a fall greater than 4" in 100' will lose entirely too much soil. The only excuse for giving more grade is to prevent breakink. If the terraces are properly constructed and maintained they will not break. Experimental results indicate that from 15 to 30 percent more soil is lost from terraces having a uniform grade of 4 inches in 100 feet than from terraces having a variable grade beginning at 1 inch in 100 feet and gradually increasing to 4 inches in 100 feet.

The practices being followed by the Soil Conservation Service in North Carolina in the construction of terraces constitutes a summary of the very best methods as determined by the ten soil erosion experiment stations over the country which have been in operation since 1929, by the work done on the other agricultural experiment stations since 1903, and by the practices of individual farmers as far back as we have records.

There are a number of things to be kept in mind in connection with the proper design and construction of a terrace.

(1) It must not cause any loss of cultivated area.

(2) It must be so constructed as to be easily crossed by machinery.

(3) The channel must be wide and flat with just enough slope to carry the water off, but not enough to cause washing.

(4) The ridge must be high enough to prevent overtopping during heavy rains.

(5) There must be a continuous grade toward the outlet to prevent excess ponding of water.

(6) The minimum number of terraces to get the desired results should be constructed.

(7) The terrace outlets must be protected so that they will not cut back into the field and cause gullies to start up the line of the terrace channel.

(8) A variable grade is to be preferred to a uniform grade.

The broad base or Mangum terrace shown in the accompanying cut with a width of 18 to 24 feet, and a height of ridge above channel of 16 to 20 inches when properly located and constructed comes nearest to meeting these requirements.

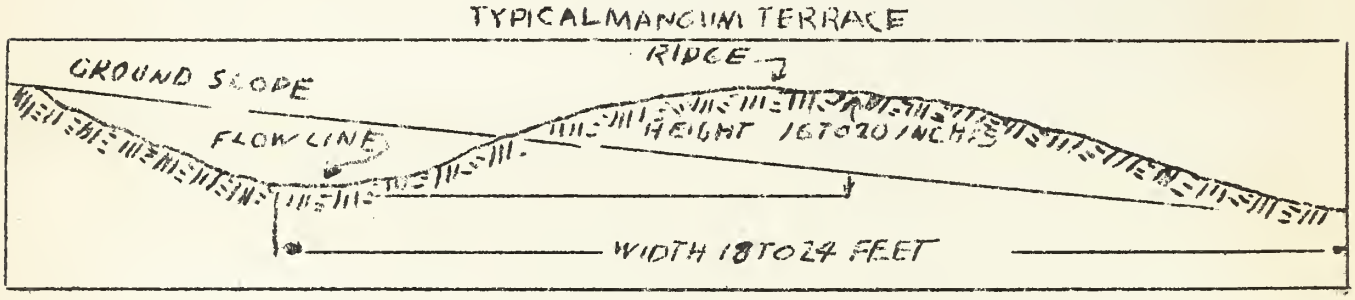


Fig. 1

A newly constructed Mangum terrace appears high to the farmer when first thrown up, but after it has been harrowed or plowed and subjected to a few heavy rains it will settle considerably. When the terrace has completely settled, if the ridge is 12 to 15 inches above the channel, it is reasonably safe. A new terrace is constructed 18 inches high to obtain the final desired height of 12 to 15 inches.

GENERAL SURVEY OF FARM - In planning a system of terraces, each field or farm has its own peculiar problems. Before any work is done, a definite study should be made of the farm, keeping in mind any details that might influence the terrace layout, such as best possible outlets, length of terraces necessary, extent of gullying, watershed area draining on the farm from above, type of soil, slope of land, adjoining property lines, location of farm buildings, road ditches and culverts, obstructions in the field, such as stumps, rocks and wet spots, and possible extension of system to include other adjoining fields.

INSTRUMENTS USED IN LAYING OFF TERRACES - The best instrument available should be used. This is always a safe statement. However, I do not believe that we are justified in using a transit or extra long telescope level in terrace work. They are cumbersome and slow in getting the readings we want. The 11" telescope Dumpy Level, with magnifying power of at least 18, gives good service and with reasonable care does not easily get out of adjustment.

The small inexpensive farm levels are sufficiently accurate but must be checked more often for adjustment.

The necessity for keeping instruments in adjustment cannot be stressed too much. For this reason, I am giving here, although I will not take the time to read it, the steps in the adjustment of a dumpy level such as we are using in the Soil Conservation Service.

DUMPY LEVEL - The dumpy level is adjusted by adjusting the bubble tube and afterward the line of sight to it.

(1) The Bubble Tube. After setting up the instrument check the bubble tube over one set of screws, swing through 180° on the vertical axis; if the bubble moves from the center, bring it half way back by the adjustment screws which raise or lower the bubble tube, relevel and repeat the test and adjustment until correct.

(2) Line of sight. Set up the instrument midway between two stakes which we will call A and B from 200 to 400 feet apart. With the bubble in the center of the tube read the rod on each stake. The difference in these readings will be the true difference in elevation of the stakes A and B even though the telescope tube is out of adjustment. For example, if the rod reading at A is 4 feet, and at B is 5 feet 1 inch, then stake A is 1 foot inch higher than stake B. Remove the level and set it up sufficiently close to stake A so that the eye end will just clear a rod held on the stake. Look through the object end of the telescope, and with a pencil point get the reading on the rod in the middle of the small spot of light that will be seen. Suppose this rod reading is 4 feet 6 inches, then knowing that B is 1 foot 1 inch lower, the reading at B from this set-up should be 5 feet 7 inches. Clamp the target on this reading and place rod on B. If the horizontal cross hair in the telescope does not coincide with the target, the telescope must be adjusted. There are usually four adjusting screws on the telescope which control the crosshairs, one each on top and bottom, and one on each side. The adjustment is made by loosening the bottom screw and tightening the top one or vice-versa depending upon whether the line of sight is to be raised or lowered.

In connection with the testing and adjusting of leveling instruments it is advisable to find the difference in elevation of two permanent points 200 to 400 feet apart which may then be used to check and adjust the level. These points should be of about the same elevation and in sight of each other. They should be of such nature that they cannot be disturbed such as foundations of buildings or long pipes driven into the ground. With this arrangement it is only necessary to set up the instrument at one of the points to check, and if needed, adjust to the true difference in elevation.

When the instrument is in regular use it should be checked at least every two weeks or oftener and immediately after any undue jars or rough handling. The more inexpensive levels are usually more likely to get out of adjustment and may need checking more often.

TERRACE SPACING - The spacing of terraces will vary with the slope of the land. Of course, there are other conditions such as type of soil, cropping system, rainfall and degree of erosion that justify a slight variation from any standard table.

A table is given here showing the fall and vertical spacing that we are using.

## TERRACING TABLE

This table gives suggested size, fall and spacing of terraces according to the slope of the land

| Slope Drop (ft.) in 100 feet | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vertical Fall Between Terraces (ft.) | $1\frac{1}{2}$ | 2 | $2\frac{1}{2}$ | 3 | $3\frac{1}{2}$ | 4 | 4.33 | 4.66 | 5 | 5.33 | 5.66 | 6 | 6.33 | 6.66 | 6.66 |
| Distance between Terraces (ft.) | 150 | 100 | 83 | 75 | 70 | 67 | 62 | 58 | 55 | 53 | 51 | 50 | 49 | 48 | 44 |

TERRACE FALL

| Length of Terrace (ft.) | Fall the 100 ft. (in.) |
|---|---|
| 0-400 | 1 |
| 400-800 | 2 |
| 800-1200 | 3 |
| 1200-end | |

Note: No terrace is constructed that carries the water in one direction for more than 1800 feet.

SIMPLE RULES ON TERRACE SPACING - A simple rule is applicable in the use of the terrace spacing table. On all slopes up to and including 6 percent take the slope of the land in feet, add 2 feet and divide by 2. For example, if the slope of the land is 4 feet in 100, then $\frac{4 \text{ plus } 2}{2}$ equals 3, which is the vertical spacing in feet to be used in terracing.

For slopes above 6 percent, take the slope of the land in feet, add 6 feet and divide by 3. For example, if the slope of the land is 9 feet, in 100, then $\frac{9 \text{ plus } 6}{3}$ equals 5, which is the vertical spacing in feet to be used in terracing.

By comparison, it will be seen that we are giving a little more spacing on the upper grades than is shown in Mr. Ramser's bulletins and repeated in a number of state bulletins.

VARIATIONS: Under the conditions we have on the soil erosion projects where we have set up a definite agreement on the cropping system for a 5-year period, we have set up the following variations in terrace spacing:

1. Three to four-year crops rotation (1 year cultivated row crop)--Increase spacing up to 25 percent, except on severely eroded land, in which case standard spacing is used.

2. Continuous close-growing crops as alfalfa or lespedeza--Increase spacing 50 percent except on severely eroded land, in which case standard spacing is used.

3. Rotation as in 1 but including strips of close-growing crops the year that cultivated row crop is grown in which width of strips equal to one-third distance between terraces--Spacing same as in 2.

4. Loose, absorptive soils with open subsoil--Spacing increased 10 percent to that shown in table.

5. Pasture land--Standard spacing.

6. Fields with variable slope--Vertical spacing is determined by taking 2/3 to 3/4 of the difference between the maximum and the minimum fall and the product added to the minimum fall; the result indicates spacing.

7. In no case is the vertical spacing between terraces permitted to be greater than 7 feet.

LIMITING LAND SLOPES - The limiting slope of land on which terraces are to be constructed should be about 12 percent. There is no doubt but that steeper land is benefited by terraces, but the increased number of terraces and the expense of construction and maintenance is such that it is a much better practice to take care of these excessive slopes by close growing crops or reforestation.

STAKING OUT THE SYSTEM OF TERRACES - Unless there is some special reason such as outlets, buildings, roads or other obstructions to be taken into consideration further down the slope, always start with the top terrace. If conditions justify starting further down the slope then extend up the slope until the top is reached.

Set up the instrument where the highest point in the field may be seen and check the grade by reading the rod at the highest point and then having the rodman pace off 100 feet down the slope and read again. Take this difference in elevation and check the spacing to be used. The locations will usually be about where the first washes have started. This may be varied slightly to take care of outlets, head off gullies or miss obstructions.

After each terrace line is staked check the slope below for locating next terrace line. If there should be above the area to be terraced additional drainage area such as forests or adjoining fields, the runoff from this overlying area should be carried off by means of a diversion ditch to protect the terrace.

Instruments should be set up at such locations as will require the fewest set-ups and at the same time reduce the length of readings to a minimum. Stakes should be set each 50 feet along the proposed terrace line except on sharp turns where they should be only 25 feet apart.

We are using 3 men to a staking crew, finding that it is not advisable to depend upon the farmer for a stake boy or for stakes. We use 1/2" x 1" x 3' stakes at $3.00 per thousand tied in bundles of 100 stakes.

CONSTRUCTION OF TERRACES - Regardless of what order is followed in staking terraces the top one must always be constructed first and each succeeding terrace down the slope completed before the next one is started.

Equipment. We have followed a policy of furnishing a grader for whatever we found in the way of power, and have Martin Ditchers, Corsicanas No. 1 and No. 2 Caterpillar Terracers, Fresnos and Slip Scrapes. We even constructed some V-drags for use while waiting for equipment.

We have terraces constructed with Martin Ditchers and Corsicanas that are just as good as those constructed with the heavier equipment, for the reason that we have stayed there until they were completed. In all of those cases we have kept a man on the machine. Under our conditions it is necessary to plow ahead of these machines.

On loose, easily worked land a direct relation may be given between these machines in the way of time necessary for the construction of terraces, but where ground is extremely hard and containing rock, stumps, roots, gullies or other obstructions, weight becomes a deciding factor and increases out of proportion the amount of time necessary with the smaller machines. In any comparison with different machines, it should be remembered that the same number of operators (2) are necessary. This factor very materially changes the comparative cost when using different outfits.

I am convinced that for our purpose the least expensive and by far the most satisfactory unit for terracing is a 40 D.B.H.P. crawler tractor with tracks 18" wide attached to a 2-wheel grader with 9' or 10' blade and weighing not less than 4400 pounds. We can definitely count on this machine sticking to the ground in our stiff clay, loose rocks and small roots and stumps, and doing the work with a minimum number of rounds, while the light machine such as the No. 1 Caterpillar, when it raises one wheel and floats along on the blade and the other wheel, rounds become an indefinite quantity.

Under the possibilities for power such as we have where the average to be found on a farm is 2 small mules, our best bet is to furnish a Fresno and insist that he spend his time making fills.

On the loose tobacco soils we have done a great deal of terracing with the horse drawn or small tractor drawn outfits to be followed by about one or one and one-half rounds with the larger units.

Construction. There are two methods followed in the actual construction of the terrace with relation to the line of stakes. One of these is to have the terrace ridge along the line of stakes, and the other is to so locate the ridge that the terrace channel will be approximately along the line of stakes. On land with a regular slope there is little difference between the results obtained by following the two methods. Where there is an irregular slope, an example of which would be to have the terrace line cross through one area where there is a slope of 10 percent, and then cross through another area farther along the line where there is a slope of 5 percent. It can be easily seen that should we start the terrace ridge along the line of stakes in this case, when we had gone up the hill 10 feet on the steep slope, we would have increased the elevation 6 inches. This would necessitate a channel 6 inches deeper on the 10 percent slope than on the 5 percent slope. Under conditions of irregular slope, we find it more satisfactory to start the terrace ridge about 8 to 10 feet below the line of stakes so that when the terrace is com-

pletely constructed the channel will be approximately along the line of stakes. In actual construction of the terrace, approximately one-third of the dirt should be moved up hill and two-thirds down hill.

Figure (2) is a copy of plan of the terracing system as outlined by the staking crew. A copy of this is given to the terrace construction crew, one to the camp foreman, together with details for outlets, and one to planting crew. Each copy is to be signed when completed, and returned for files.

With a 40 H.P. crawler tractor and equivalent terracing machine equipped with 9' blade and end bits, we are constructing a terrace 18" high, 18-24 feet wide and with a channel 8 feet wide in 5 rounds. The chart and set of pictures attached show the progression of one of these jobs on a 9% slope. We have to make an extra trip with the 8' blade grader to get the same results.

There has been a great deal of discussion and reports about terraces constructed in 3 or 4 rounds with similar equipment. We have not been able to get the cross section we want in less than 5 rounds.

With the same units we are averaging about 500' of terrace per hour with our best operators. In this connection it is well to explain that our fields are comparatively small requiring in many cases terraces only a few hundred feet long. We have enough stumps and rocks to justify two dynamite crews clearing the lines after stakes have been set. All of our tractors are equipped with lights so that we get 80 hours or a double shift out of the machines each week.

After terraces are constructed, they should be rechecked with instruments to be sure that there is a continuous grade toward the outlet in the channel, and that there is a minimum height of ridge above channel of 18 inches all along the line. Necessary fills in gullies or other low places should be made immediately, as well as high points in the terrace channel should be cut down to grade in order that there will be a continuous grade toward the outlet. In making fills it is well to remember that on the average we have a settling of about 20 percent. For this reason, where there is a deep fill of several feet, it can be easily seen that it will be necessary to raise this fill several inches higher than the remainder of the terrace ridge so that there will not be a low place when the loose dirt has settled.

Up to January 19 we had terraced 5,317 acres; since July 1934 on 355 farms. Our average is about 8 acres per mile. Our farms average about 70 acres.

## POINTERS IN CONSTRUCTING TERRACES

(1) Always construct and complete top terrace first, and proceed down the slope.

(2) Cross gullies directly, and build up terrace at the point of intersection with earth fill.

(3) Avoid sharp turns in terrace lines.

(4) Check grades, height, and width of the completed terrace before leaving it.

(5) Construct the outlet immediately after the terrace is complete unless it empties to a sodded area already established.

(6) Consult table for size of outlet necessary to care for water drained from the area terraced.

CARE OF TERRACES - For the sake of keeping up the terraces, as well as reducing erosion to a minimum, all breaking and cultivation of land should be parallel to the terraces. New terraces should be checked immediately following each heavy rain to see if there are any weak places and see if outlets are open and working properly, and any necessary fills made. After the first year, if this plan is followed, the terraces will be sufficiently well established so that they will require very little attention.

The necessary maintenance of broad base terraces is greatly simplified by using the proper method in breaking the land. The best practice is to always start the list on top of the terrace ridge (Fig. 3) turning the dirt to the ridge from both directions until the bottom of the channel is reached on the upper side. Then start another list 8 to 10 feet above the channel and list to this until the channel is reached. Plow out the remaining strip as a separate land. This method will have a tendency to keep the channel open as well as the ridge up.

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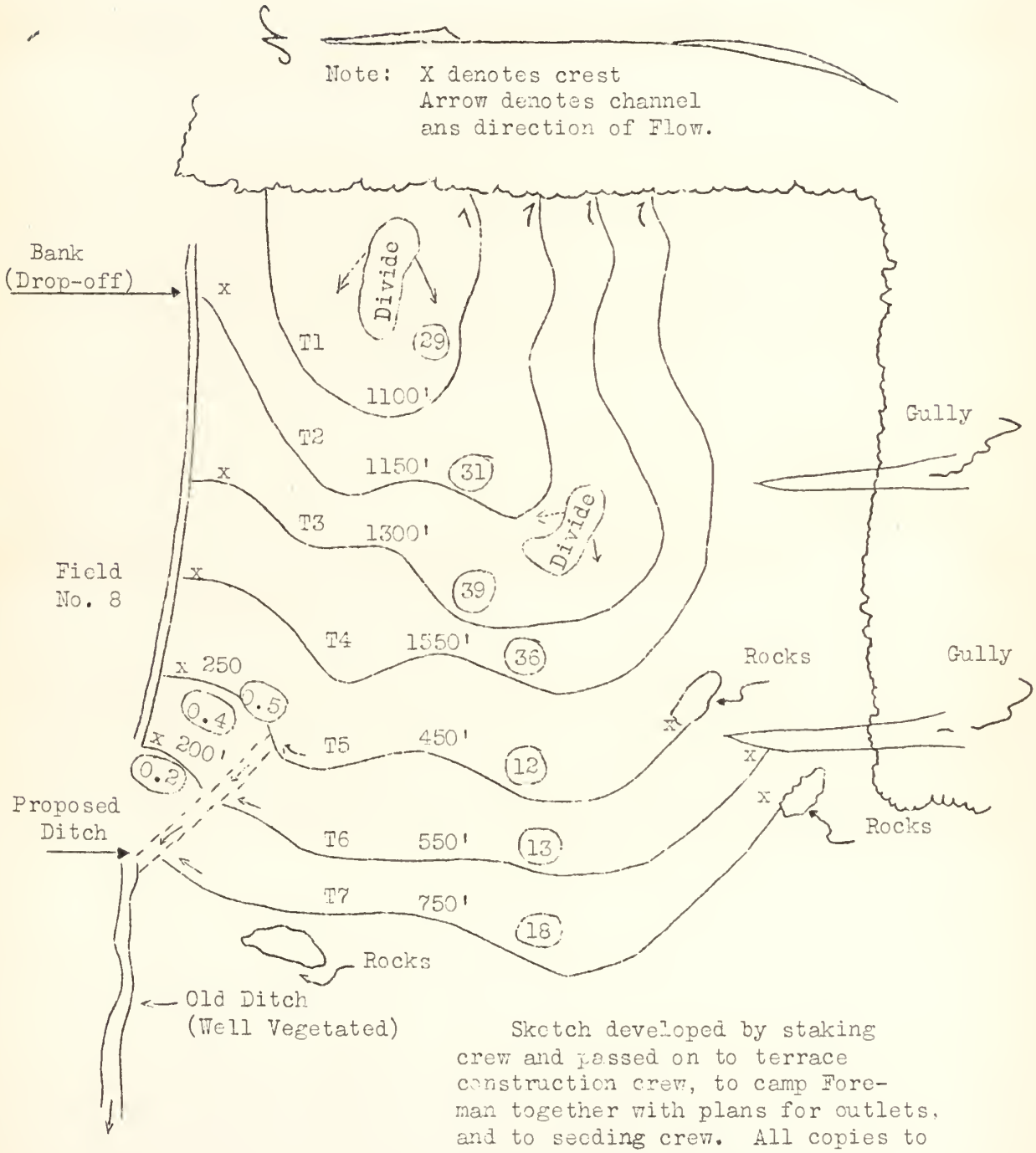
Field No. 7  8 Man Hours
Vol. 28 P 34  1-18-35  Adams




Sketch developed by staking crew and passed on to terrace construction crew, to camp Foreman together with plans for outlets, and to seeding crew. All copies to be signed and returned for files when work has been completed.

Fig. 2

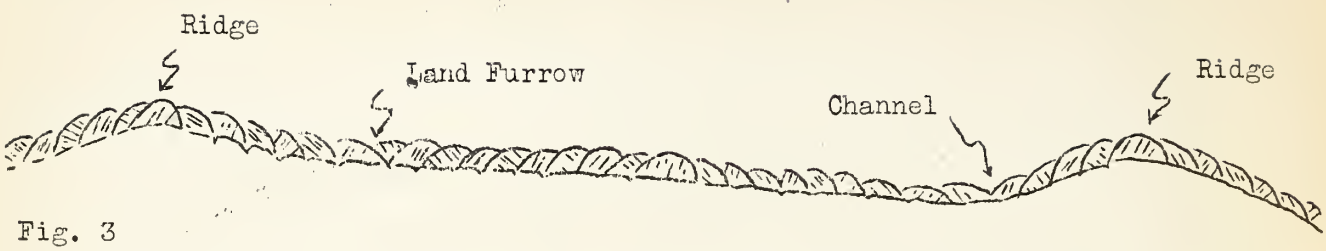



Fig. 3

One variation from this, (Fig.4), is to start the list on top of the terrace ridge turning the dirt to the ridge from both directions as before. After the entire terrace has been plowed in this way, the strip between each two succeeding terraces may be plowed as a separate land with the final furrow coming approximately half way between terraces. The exact location of this final furrow may be varied by lising more or less to one terrace than the other. With this method it is usually necessary to brush out the channel with a light drag or grader after the plowing has been completed.

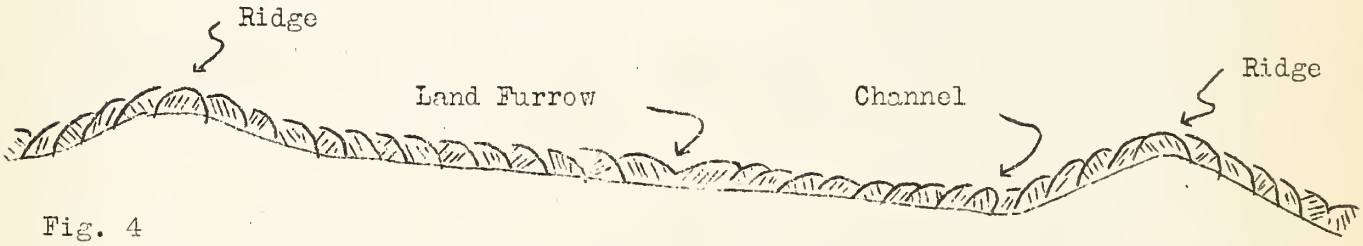



Fig. 4

The best practice to be followed in the growing of row crops on terraced fields is to start the first row along the top of the terrace ridge (Fig. 5) and continue them down hill parallel to the terrace until the next terrace channel below is reached, ending all point or short rows in the terrace channel. Then beginning atop this terrace the operation is repeated. In this way all point rows terminate in the terrace channel. This permits the channel to be kept open and the thinnest soil in the field used as a turn row.

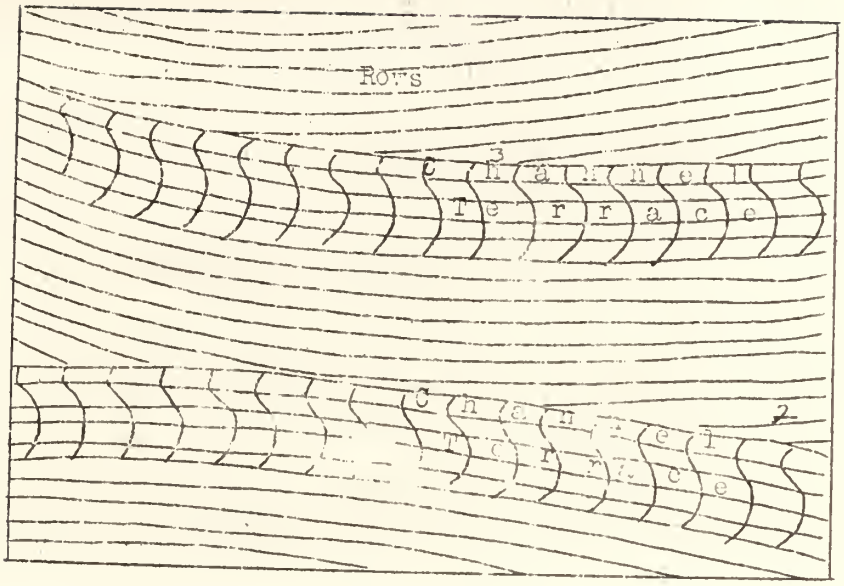



Fig. 5

One other method of running rows with relation to the terraces is to start the rows on top of each terrace running them parallel to the terrace until a point midway between the terraces is reached. Then taking up the irregular space midway between the terraces with short or point rows. This system possibly retains more soil and moisture than the one described above, and is often used in the growing of cotton, corn and some of the other row crops. It should not be used in the growing of tobacco as this crop requires quicker drainage after a rain than most of the other row crops.

TERRACE OUTLETS AND OUTLET CHANNELS - The protection of a terrace outlet as referred to here is the control of the outlets of individual terraces, while the outlet channel refers to a channel designed to carry the water from one or more terrace outlets.

The proper protection of outlets and outlet channels is one of our most expensive items in connection with terracing. It is necessary to take advantage of every opportunity in locating these in such a way as to reduce the first cost and minimize any necessary upkeep. If outlets are not protected there is a good chance of a gully backing up the channel.

The best places for outlets are on sodded areas such as pastures, meadows, wooded areas with thick underbrush, natural draws or low places in the field where a wide sod strip may be established and used as a combination outlet and meadow for the production of hay, and natural streams or drainage ditches. It may be necessary to use brush, logs, stakes, loose rock, wire checks, sod strips or other temporary means to take care of outlets until permanent plantings may be established. Where the fall is too great to be handled by these means, it is necessary to use some type of permanent structure such as rock masonry or concrete.

Where outlet channels extend through a low place in the field it is necessary to lay out the system of terraces so that one structure across the channel will protect a terrace coming from each side. These outlet channels can usually be located where the slope is fairly flat.

We have been able to establish a sod in outlet channels on grades up to 6 percent after the terraces were constructed. On slopes above 6 percent we reduce the slope by means of permanent structures to a slope where sod may be established. Where it is not possible to establish the sod ahead of the terracing program, these outlet channels require some temporary structures to hold them until the sod is established, the number and kind depending upon the grade. We use a definite check of wire, sod bags, loose rock or other temporary structures at the terrace outlets and distribution boards, sod strips, rock aprons or sod bags distributed between these. On the flatter slopes up to 2 to 3 percent, the distribution boards alone have given good results.

We are starting a program this spring of seeding these outlet channels ahead of the terracing program as far as possible. I am sure that on a long time program it would be best to seed these channels down a year ahead of the program.

It is necessary in some cases to establish outlet channels along the property lines and protect them by means of a combination of sod and either temporary or permanent structures. We are getting more optimistic about establishing sod in these channels and in order to allow for silting that may take place we are giving the terraces a four-inch drop into the bottom of these channels in addition to the regular grade of the terrace. This drop is protected by loose rock.

Road ditches are sometimes used as outlets, but should be avoided where possible as there is always a chance of damage to the road unless the ditches are enlarged and properly protected. In many cases road culverts drain on to the farm and must be taken into consideration in the location and size of outlet channels.

In designing outlet channels a maximum depth of 6" of water is used where there is a slope of 6 percent. A depth of 8" is used for all slopes up to 5 percent. The table and chart below are used in this design.

RATES OF RUNOFF

BASED ON RAINFALL FREQUENCY ONCE IN TEN YEARS
(For Unterraced Rolling Cultivated Land)

From Ramser's Grouping No. 3

| Watershed Area in Acres | Cubic feet per sec. | Watershed Area in Acres | Cubic feet per sec. |
|---|---|---|---|
| 1 | 6.25 | 20 | 78.00 |
| 2 | 11.25 | 21 | 80.50 |
| 3 | 17.50 | 22 | 83.00 |
| 4 | 22.50 | 23 | 85.00 |
| 5 | 27.00 | 24 | 87.50 |
| | | 25 | 89.00 |
| 6 | 31.50 | 26 | 91.25 |
| 7 | 36.25 | | |
| 8 | 40.00 | 27 | 93.50 |
| 9 | 44.00 | 28 | 95.00 |
| 10 | 48.00 | 29 | 97.50 |
| | | 30 | 98.50 |
| 11 | 52.00 | | |
| 12 | 55.00 | 40 | 125.00 |
| 13 | 58.25 | 50 | 150.00 |
| 14 | 62.25 | 60 | 170.00 |
| 15 | 64.50 | 70 | 200.00 |
| 16 | 67.50 | 80 | 220.00 |
| 17 | 70.00 | 90 | 245.00 |
| 18 | 73.00 | 100 | 260.00 |
| 19 | 75.50 | | |

For hilly (10-30%) cultivated multiply the values of the table by the factor 1.2.

For hilly (10-30%) pasture multiply the values of the table by the factor 0.7.

For hilly (10-30%) timber multiply the values of the table by the factor 0.35.

For rolling (5-10%) pasture multiply the values of the table by the factor 0.6.

For rolling (5-10%) timber multiply the values of the table by the factor 0.3.

Note. C. E. Ramser recommends following reductions in runoff for terraced land:

| | |
|---|---|
| 1 acre or less | .40 |
| 1-10 acres | .30 |
| 10-30 acres | .25 |
| 30-100 acres | .10 |

Fig. 6.

GULLY CONTROL - Small gullies appearing in the field can be controlled by proper terracing of the field. It is generally found that the gullies will head at approximately the point where the top terrace should be located. When the terrace is constructed, all the watershed above the gully is cut off and washing prevented. By crossing gullies directly with the terraces, the silt that is carried along the flow line is deposited in the gully and will help to fill in the low places. Where gullies are too large to be crossed by terraces, it is advisable to cut off the head water by means of one or more terraces and then plant the gully with either trees or vines to assist nature in reclaiming it. It may be necessary to put in some brush or wire checks and possibly a straw mulch to hold moisture necessary in the growing of these plantings.

# TERRACING PROBLEMS IN THE NORTH CENTRAL STATES

by

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S. C. S. Project #1, La Crosse, Wisconsin

The Coon Creek project, consisting of 92,000 acres, is located just outside of La Crosse, Wisconsin, in the southwestern part of the state. The topography is very rough, many slopes exceeding 40 and even 60%. This land, of course, is worthless for either cultivation or pasture. The cultivated land, particularly in the western part of the watershed, consists of relatively narrow ridge tops and valley floors. None of the valley land has been considered for terracing, as the farmers have not had enough experience with terraces for us to expect them to take care of diversion ditches. Little terracing has been done in the western part of the valley, even on the upper plateau, because of the difficulty in safely conducting the runoff from the terraces down the slopes, which exceed 500 feet in height, to the valley floor.

Before the advent of the Soil Conservation Service and the present E.C.W. program, terracing was very little known in either Wisconsin or Minnesota. The Wisconsin Extension Service had held quite a number of terracing demonstrations in this part of the state, but the idea of terracing had spread very slowly from these demonstrations.

Three years ago the Upper Mississippi Valley Soil Erosion Experiment Station was established. Terraces and many other erosion control measures were set up at that time, but neither Mr. Davis nor myself made any attempt to advertise the work done until the experiments were more fully established, consequently this work was not known to a very large number of farmers. When the Soil Conservation Service began its activities in the Coon Creek watershed it was found that most of the farmers had only the vaguest sort of an idea as to what we meant by terracing. Most of them remembered pictures of bench terraces they had seen in some old geography. By thinking of bench terraces most of them became prejudiced against terracing. There were a few, however, who were willing to have a small field worked on. From the time the actual field work started, the attitude toward terracing has been changing and by the middle of the summer, after those who had terraces discovered that the difficulties they expected to find in working them were mostly imaginary, many of those who were not pleased in the spring were asking us to terrace additional areas. Previous to this time we had been rather lax in accepting areas for terracing. Our attitude was that we could afford to terrace some fields, which we would not refuse as impractical, so we would have terraced fields throughout the area for possible future cooperators to see. Since the idea of terracing has become established we have been very careful to accept only those fields which we feel can be terraced practically.

While terracing had been done for a good many years in this country, no terracing program before this one, being carried out by the Soil Conservation Service, has been as widespread or as complete in its scope. In a

program of this kind much information of value in regard to terracing should be obtained. In this paper I wish to bring up some of the questions which have come up on our project and give what we think are the answers. It is expected that many of you will disagree with me on the points discussed, as my remarks in most cases are based on observations made in only one section of the country.

The question of where and when it is practical to terrace and what factors influence it, is probably the first one to be answered. The most important factor influencing terracing is probably the slope of the land. In the Coon Creek watershed we have an arbitrary upper limit of 10 to 12%, however, things other than slope may either raise or lower this figure. It is obvious that a steep terrace embankment offers less of an impediment to small horse-drawn implements than to large tractor-drawn machinery. Thus, the type of machinery in use on a farm is an influence in determining how steep a slope we will terrace. The degree of erosion already present will also change the point at which we stop terracing. In our project there are several fields of from 12 to 20% slope which are very badly riddled with small gullies. These fields may be lost or very nearly lost, as far as cultivation is concerned, due to the presence of these small ditches, which have reached a point at which it is no longer possible to get them seeded without some mechanical means of control. Dams or terraces offer the only means of reclaiming these fields, and terraces are by far the most practical, as the ditches are not only filled but the water is removed before it can do any further damage. In these cases it is decidedly practical to terrace on steep slopes, even though the terrace ridge offers so great an obstacle that it cannot be farmed. In that case, the area between the terraces available for cultivation should remain productive for a long time, if reasonable precautions are used in breaking the strips and a good crop rotation is followed.

The present and potential value of the land in question must, at times, be very carefully considered if we are not to spend more for terracing than the land is worth. We must ask ourselves; what will the land be worth in, say, 5 years, if it isn't terraced, and will it be worth enough more if it is terraced, to pay for the cost? As an example of this, there is the Lester Mundstock farm in Coon Creek. On this farm, approximately 40 acres were terraced, and at least half of this was very badly gullied. In fact, so much so that it required no stretching of the imagination to visualize this land as worthless for anything more than pasture, in less than five years. The cost of terracing this twenty acres was slightly over $17.00 per acre. Over half of this cost was in filling ditches so the terracing outfit could cross them, and in building up the low places in the ridge. Since this field has been terraced and seeded it will easily be worth from $50.00 to $60.00 per acre, while without the terracing it was practically worthless. It is necessary to be careful in doing this type of reclamation, however, or the cost of the work does not exceed the value of the land.

This brings us to the influence which the various soil types have on terracing. It is obvious that some soils are so poor that they do not warrant the expenditure of either time or money. This may be because the soil is naturally poor, or it may be because it is already so badly eroded

that it will not produce crops. We know also that some soils are more erosive than others. The engineer should be able to determine from his observations the relative erosiveness of different classes of soils. I am firmly convinced that under most conditions terraces should be built large enough and shaped so that the amount of runoff from the space between terraces is not a limiting factor in spacing them. The principal reason for this, is the fact that a large terrace with long gentle slopes and a wide flat channel is enough easier to work to more than pay for the additional cost of construction. The exception to this is when terraces are built on steep land and it is not expected that the ridge will be worked. If this is true, then the spacing of terraces depends entirely on how wide a strip can be left unprotected on any slope and any soil, without having undue sheet erosion between them. If the difference in the erosiveness and various soils, which are present even within the boundaries of one project, is disregarded, it is a simple matter to work out a table by which terraces may be spaced, in fact there are such tables which have been made up from data obtained by the Soil Erosion Experiment Stations. I think, however, that we are unfair to terraces and to the farmer on whose land the terraces are built, unless, by observation, we determine whether the terraces on this land must be spaced closer or may be spaced wider than is shown in the tables.

In the Coon Creek area there is a type of soil, known to the soils men as Dubuque. This soil is developed from the residual limestone and has relatively thin layer of friable top soil. The sub-soil is a sticky red clay which is very steny, in fact the ledge limestone may be very close to the surface. In soils of this type the cost of terracing may be so high as to be prohibitive. The rocks, of course, are a distinct impediment to terracing, but not as much so as the sticky red clay which will not scour on the blade. The exposed sub-soil in this type is extremely slow to come back to a productive state. This fact, along with the expense involved in the construction, has led us to avoid this soil whenever possible. It is doubtful whether this soil is ever worth the cost of terracing.

The question of suitable outlets is the one most apt to cause trouble for the engineer laying out a system of terraces. If there is a natural outlet available, the engineer is lucky, but he should be sure that the vegetative cover is dense enough to absorb the water discharged on it, or strong enough so that it won't be washed out by the spring rains. If the terraces are to empty into an ungrazed woodlot or pasture, there is very little danger unless several terraces empty together in a place from which the water will concentrate quickly. If, however, the outlet is in a pastured area the sod must be stronger or the slope must be such that the water will spread rather than concentrate.

Many times sod draws are present in the fields to be terraced. These are usually safe if they are wide enough. When they are used the water channel should be inspected far enough down the slope to be sure that no damage will be done if a larger quantity is emptied into it. When the drainage area is not increased it is safe to assume that the hazard has not been increased, as the time of concentration of the runoff is usually lengthened by the presence of the terraces. It is necessary, however, in approximately half the cases to construct artificial outlets, at least to lead the water away from the cultivated field. These ditches may be pro-

tected by permanent or temporary dams or by the use of vegetative cover. In the Coon Creek watershed we started by using pole dams for protection, then it was found that masonry dams could be constructed for approximately the same cost. Quite a few structures of this type were built before it was found that completely sodding a waterway was the most logical way to protect these artificial ditches in our area. Very little work is done toward protecting outlets outside the cultivated fields, because we do not empty these artificial outlet channels in places which require protection, except in extreme cases. The artificial waterways are, as they have been built since the middle of the summer, flat bottomed to insure an even distribution of the water, and are built with a cross-section large enough to handle the maximum runoff without the velocity of the water exceeding 5 feet per second. Thus, the width of the ditch depends upon the volume of water and the slope of the ditch. A table has been worked out from Manning's Formula, which gives the width of a channel necessary for varying quantities on slopes up to 25%. 0.040 has been used as the value of "N". It is assumed that it is impractical to sod artificially, ditches wider than 15 feet, unless absolutely necessary. The logical way to construct these outlets is to shape and grade the channel and seed it. Then, after a few years, during which the sod has had time to become well established, the terraces should be constructed and emptied into it. The necessity of completing our program by June 30, 1935, precludes this method of construction and necessitates the grading of the outlet channels at, or after, the time the terraces are built and the immediate protection of the channel by sodding. On the Coon Creek project, it has been found that this method is less expensive than the building of structures, and this has had a distinctly better psychological effect on the farmers. This type of outlet requires the presence of good sod within a reasonable distance. Beginning with conditions as left by the terracing crew, a group of seven C.C.C. boys with an S.E.S. foreman in charge, and a one-half ton pick-up, shape the ditch, cut, haul, lay, and tamp the sod at the rate of one square yard per man hour. The sod is cut in strips long enough to extend the width of the ditch and is laid across at right angles to the direction of flow, with the ends of the strips extending well up the banks. During the dry weather all of the sod was watered after it was laid. That laid late this fall was fastened down with staples made from No. 9 wire. It is doubtful if this is necessary but the extra precaution was taken to safeguard these ditches from damage at time of spring runoff. When it is necessary to construct an outlet on a gradient greater than 12 or 15%, level spreaders of masonry or creosoted lumber are placed every 15 to 20 feet to prevent the concentration of water in any one portion of the outlet ditch. Outlet work has been done on 50 farms and protects the terraces on 597 acres, or approximately 42 percent, of the area terraced to date.

It has been our policy on the Coon Creek project to built terraces which will hinder the operation of the farm machinery already present in the valley, as little as possible. There are several reasons for the adoption of this policy, the most important of which is the fact that the farmers will continue to use that equipment in working their terraces, in spite of all the agitation towards new and better farm machinery for use on terraced land. Since the idea of terracing is new in Coon Valley, we are trying to remove all possible objections toward terraces,

at least until the farmers themselves have had a chance to see the benefits derived. The machinery problem has had more weight than any other one thing in determining the shape of the terraces on this project.

In all terraces there are three distinct slopes or surfaces, any one of which should be wide enough to allow any machine which may be used, to operate on it efficiently. Not only must these slopes be wide enough, but the surface of that slope must lie in as nearly a straight line as possible. A side delivery rake is an example of an implement that will not operate on a curved uneven surface. Each of these slopes must be at least 8-1/2 feet wide. With this in mind the following specifications have been set up as an ideal, on an 8% slope. The lower slope of the ridge 12 feet wide, the upper slope of the ridge, 8-1/2 feet, the channel level for 4 feet, and the back slope 12 feet wide. The freshly built unsettled ridge must have a minimum height of 20 inches.

The slope widths, as given above, are not a rigid requirement but are approximated as closely as possible. 8 feet, however, is the absolute minimum width allowed for any slope.

The four foot channel width not only gives a larger channel capacity, but keeps the velocity of water in the channel as low as possible and separates the two opposite slopes of the channel, making them much easier to work.

This type of terrace does leave exposed a relatively wide strip of sub-soil, from 6 to 12 feet, but in all cases the farmers who are having terraces built, have agreed that they would rather have this unproductive strip for a few years than to have terraces difficult to work, for the rest of their lives. This point has worried the farmers in Coon Valley very little, because they can understand, when it is explained to them, that if this strip is manured heavily it will be only a short time until the productivity returns. The crops on the terraces at the Experiment Station, which have been built 3 years, showed no deficiency on the back-slope this year.

Many of the agricultural engineers have been advocating rather drastic changes in farm machinery for use on terraced land. I thoroughly agree that many changes can be made in farm machinery, but I also think that we should be sure of what is needed and all the consequences of our recommendations, before we make them. It is true that most of our farm machinery has been designed for use on flat land and that many improvements can be made in the machines for use in rolling, uneven fields, but we should not use terraces as a sole excuse for any of these proposed changes. Most of the changes being recommended are for increased flexibility in the equipment. In some implements this can be done without much change. For instance, in a grain drill, provision could be made for the individual discs or hoes to have more independent movement, even if individual depth gages were required, while in implements such as a Cultipacker, landroller, grain binder, disc-harrow or side-delivery rake, increasing the flexibility would also increase the complexity. Therefore, these machines would either be more expensive or shorter lived. We, as agricultural engineers, do not

want to be responsible for this unless these changes are necessary. There is not much point in redesigning any one of these machines so that it will work more effectively at all angles over a terrace embankment, unless it makes this machine more efficient in operating on unterraced land or the spaces between the terraces, which, after all, constitute by far the greater portion of our farms.

It might be a different story if we could practically redesign all of the implements which may be expected to operate over a given set of terraces. If we can't do this, we must build the terraces to accommodate the least flexible of all, which, in Wisconsin, is the side-delivery rake. The terrace cross-section which has been described will allow the use of a side delivery rake or any other implement commonly used on our project, provided of course that all work is done parallel to the terraces. Each slope must be worked as a unit, with the laps, between trips, in the channel and on the peak of the ridge. The point I should like to make is this; if we are to recommend changes in machinery design, let us consider carefully the consequences of our proposed changes, and then, if they seem justified, make our recommendations on the basis that the new machines will operate more efficiently on rough land and that the need for the changes was merely accentuated by, not made necessary by, the presence of terraces.

With these slope width specifications, the width of the terrace does not change much as the slope increases, as long as the ridge is to be farmed. On very steep land, when it is expected that the terrace will be kept seeded, the ridge becomes very much narrower.

The proper grade for terraces has been pretty well worked out by the various Soil Erosion Experiment Stations. Those used on the Coon Creek project are those which proved to be most practical at the Upper Mississippi Valley Soil Erosion Experiment Station, located just outside of LaCrosse, Wisconsin.

The grades used are as follows: the first 300 feet from the upper end has one inch fall per 100 feet, the next 300 feet - 2 inches per 100 feet, and so on, except that a grade of 5 inches or .4 feet per hundred, is never exceeded. If the terrace is over 1500 feet long, some may be left level at the upper end, or the interval between changes in grade is increased. The grades given to terraces should vary with the soil types. On more absorptive soil, the grade can be lowered, giving more water a chance to be absorbed in the channel. The erosiveness of the channel is the limiting factor in increasing the grade. I don't think that there is ever any reason for increasing the grade above 6 inches per 100 feet. When extremely low grades are used the channel will fill up much faster, but a correspondingly greater amount of soil will be saved.

Terraces have been in use long enough in various parts of the United States to show that it pays, not only from the point of helping to curtail erosion, but also that the chance of failure of the terrace is greatly diminished, if all tillage operations are carried on parallel to the terraces. All of the farmers in the Coon Creek watershed for whom we have built terraces, have agreed to work with the terraces and to place

the back furrows, when plowing, on the ridge. Of course it doesn't hurt the terraces any if the grain or hay harvesting equipment is used across them. This can be done successfully with either a grainbinder or mowing machine.

I believe that it is as much a part of the Agricultural Engineer's responsibility to try to help work out a satisfactory farming system, which will enable the farmer to get as much work done with as little effort as possible and still get the maximum amount of protection from erosion, as it is for the engineer to build the terraces themselves. In sections where a large proportion of row crops are grown, probably all that can be done is to show the farmer how he can place and work his point rows to the best advantage, but in other sections, where row crops take up a relatively small portion of the cultivated area, perhaps they can be worked in strips so that there are no point rows. The hay and grain in this system would absorb the irregularities. I do not have the space to discuss this method in detail as there are many factors to be considered, such as whether the land is to be pastured after the crops are harvested or not. There are also many, as yet, unknown factors, such as how much time is lost in cultivating and harvesting the point rows of a row crop by all of the various methods in use in this country today. There are so many different systems of farming in use that each should be studied by the engineer in his locality, to determine just how each can be changed the least and still do the most good. Most of the farming methods have become traditional with the people that they can only be changed gradually and by constant educational work.

As nearly as I can find out, the Soil Conservation Service has used nearly every possible kind of contrivance which will do the job, to build terraces. All of these machines probably have their good points and also their bad ones. In Wisconsin we were confronted with the problem of not knowing how much terracing there would be. Terracing was so new that it was very doubtful whether many farmers would want it done. We did know that whatever areas were signed for terracing would be quite widely separated and that our equipment should be as mobile as possible. I am a firm believer in using as large equipment as can be used profitably, but naturally the larger the equipment is, the more work it must do to pay for itself. It was felt that we should have equipment that could be transported by truck. Six Caterpillar "22" tractors and No. 1 terracers were purchased last spring. As the work progressed it became evident that we could use some larger equipment. This fall, two Caterpillar "35" Diesels and No. 2 terracers were purchased. There is not much doubt but that we would have been rather severely criticized if we had attempted to use equipment of this size last spring, because the farmers are not used to the sight of large equipment on their farms.

The growing season in Wisconsin is so short that it is occupied by the crops a very large percentage of the time that the ground is unfrozen. The ground is free for about a month in the spring, and some of it in the fall from about the middle of August to the middle of November, making about four months out of the year when terracing can be done. The six outfits, in these four months, have completed 110 miles of terraces,

giving direct protection to 1,154 acres and indirect protection to 287 acres, or a total of 1,441 acres. In building the terraces, most of the earth is moved from the upper side, even on the flatter slopes. Next spring it is expected that more work can be done towards finding out and showing the crews how the terraces can be built most efficiently.

During the past summer it has become increasingly evident that the farmers in the northern states cannot do much terracing for themselves, for the simple reason that they are either sowing or harvesting crops during this four month period when terracing can be done. If terracing is ever to become popular in this part of the country it will either have to be Government supervised (Federal, State or County), or by private contractor. In either case I am sure that there is no place for small equipment. The proper size of the equipment will depend largely on the size of the project. Whatever equipment is used must be strong enough to withstand extremely rocky conditions, which are common throughout the area.

TABLE OF WIDTHS FOR FLAT BOTTOM, SOD, TERRACE OUTLET CHANNELS

| Discharge in c.f.s. | Slope in Percent 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 4 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 5 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 6 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 7 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 8 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.5 |
| 9 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.5 | 7.0 | 7.5 |
| 10 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.5 | 7.0 | 8.0 | 8.0 |
| 11 | 6.0 | 6.0 | 6.0 | 6.0 | 6.5 | 7.5 | 8.0 | 8.5 | 9.0 |
| 12 | 6.0 | 6.0 | 6.0 | 6.5 | 7.5 | 8.0 | 8.5 | 9.5 | 10.0 |
| 13 | 6.0 | 6.0 | 6.5 | 7.0 | 8.0 | 8.5 | 9.5 | 10.0 | 10.5 |
| 14 | 6.0 | 6.0 | 7.0 | 7.5 | 8.5 | 9.5 | 10.0 | 11.0 | 11.5 |
| 15 | 6.0 | 6.5 | 7.5 | 8.0 | 9.0 | 10.0 | 11.0 | 11.5 | 12.5 |
| 16 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 10.5 | 11.5 | 12.5 | 13.0 |
| 17 | 6.0 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.0 | 13.0 | 14.0 |
| 18 | 6.5 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 14.5 |
| 19 | 7.0 | 8.0 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.5 | 15.0 |
| 20 | 7.0 | 8.5 | 10.0 | 11.0 | 12.0 | 13.5 | 14.5 | 15.0 | 16.5 |
| 21 | 7.5 | 9.0 | 10.5 | 11.5 | 13.0 | 14.0 | 15.0 | 16.5 | 17.0 |
| 22 | 8.0 | 9.5 | 11.0 | 12.0 | 13.5 | 14.5 | 16.0 | 17.0 | 18.0 |
| 23 | 8.5 | 10.0 | 11.5 | 12.5 | 14.0 | 15.5 | 16.5 | 18.0 | 19.0 |
| 24 | 8.5 | 10.5 | 12.0 | 13.0 | 14.5 | 16.0 | 17.5 | 18.5 | 19.5 |
| 25 | 9.0 | 11.0 | 12.5 | 13.5 | 15.5 | 16.5 | 18.0 | 19.5 | 20.0 |
| 26 | 9.5 | 11.0 | 13.0 | 14.5 | 16.0 | 17.5 | 18.5 | 20.0 | |
| 27 | 10.0 | 11.5 | 13.5 | 15.0 | 16.5 | 18.0 | 19.5 | | |
| 28 | 10.0 | 12.0 | 14.0 | 15.5 | 17.0 | 18.5 | 20.0 | | |
| 29 | 10.5 | 12.5 | 14.5 | 16.0 | 17.5 | 19.5 | | | |
| 30 | 11.0 | 13.0 | 15.0 | 16.5 | 18.5 | 20.0 | | | |
| 31 | 11.0 | 13.5 | 15.5 | 17.0 | 19.0 | | | | |
| 32 | 11.5 | 14.0 | 16.0 | 17.5 | 19.5 | | | | |
| 33 | 12.0 | 14.0 | 16.5 | 18.0 | 20.0 | | | | |
| 34 | 12.5 | 14.5 | 17.0 | 18.5 | | | | | |
| 35 | 12.5 | 15.0 | 17.5 | 19.0 | | | | | |
| 36 | 13.0 | 15.5 | 18.0 | 20.0 | | | | | |
| 37 | 13.5 | 16.0 | 18.5 | 20.0 | | | | | |
| 38 | 14.0 | 16.5 | 19.0 | | | | | | |
| 39 | 14.0 | 17.0 | 19.5 | | | | | | |
| 40 | 14.5 | 17.0 | 20.0 | | | | | | |

Widths Shown are in Feet.

Note: Under Ordinary Conditions Width of Channel is to be Limited to 15.0 Feet, Extraordinary Conditions May Permit Channel Widths up to 20.0 Feet.

The Channel Widths in the Above Table are Derived from Mannings Formula:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \text{ and } Q = a V$$

V = 5 feet per second. n = 0.040. R = Hydraulic Radius.
S = Slope in Feet per Foot. Q = Discharge in Second Feet. a = area in sq.ft.

TABLE OF WIDTHS FOR FLAT BOTTOM, SOD, TERRACE OUTLET CHANNELS

| Discharge in c.f.s. | Slope in Percent 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|
| 3 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 4 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 5 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 6 | 6.0 | 6.0 | 6.0 | 6.0 | 6.5 | 6.5 | 7.0 | 7.5 |
| 7 | 6.0 | 6.5 | 7.0 | 7.0 | 7.5 | 8.0 | 8.0 | 8.5 |
| 8 | 7.0 | 7.5 | 8.0 | 8.0 | 8.5 | 9.0 | 9.5 | 9.5 |
| 9 | 8.0 | 8.5 | 9.0 | 9.0 | 9.5 | 10.0 | 10.5 | 11.0 |
| 10 | 9.0 | 9.5 | 10.0 | 10.5 | 11.0 | 11.0 | 11.5 | 12.0 |
| 11 | 9.5 | 10.0 | 10.5 | 11.5 | 12.0 | 12.5 | 13.0 | 13.5 |
| 12 | 10.5 | 11.0 | 11.[illegible] | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 |
| 13 | 11.5 | 12.0 | 12.5 | 13.5 | 14.0 | 14.5 | 15.0 | 15.5 |
| 14 | 12.0 | 13.0 | 13.5 | 14.5 | 15.0 | 15.5 | 16.0 | 17.0 |
| 15 | 13.0 | 14.0 | 14.5 | 15.5 | 16.0 | 17.0 | 17.5 | 18.0 |
| 16 | 14.0 | 15.0 | 15.5 | 16.5 | 17.0 | 18.0 | 18.5 | 19.5 |
| 17 | 15.0 | 16.0 | 16.5 | 17.5 | 18.5 | 19.0 | 19.5 | |
| 18 | 15.5 | 16.5 | 17.5 | 18.5 | 19.5 | 20.0 | | |
| 19 | 16.5 | 17.5 | 18.5 | 19.5 | 20.0 | | | |
| 20 | 17.5 | 18.5 | 19.5 | 20.0 | | | | |
| 21 | 18.5 | 19.5 | 20.0 | | | | | |
| 22 | 19.0 | 20.0 | | | | | | |
| 23 | 20.0 | | | | | | | |

Widths Shown are in Feet.

| Discharge in c.f.s. | Slope in Percent 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|
| 3 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 4 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| 5 | 6.5 | 6.5 | 6.5 | 7.0 | 7.0 |
| 6 | 7.5 | 8.0 | 8.0 | 8.5 | 8.5 |
| 7 | 9.0 | 9.0 | 9.5 | 9.5 | 10.0 |
| 8 | 10.0 | 10.5 | 10.5 | 11.0 | 11.5 |
| 9 | 11.5 | 11.5 | 12.0 | 12.5 | 13.0 |
| 10 | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 |
| 11 | 14.0 | 14.5 | 14.5 | 15.5 | 15.5 |
| 12 | 15.0 | 15.5 | 16.0 | 16.5 | 17.0 |
| 13 | 16.5 | 17.0 | 17.5 | 18.0 | 18.5 |
| 14 | 17.5 | 18.0 | 19.0 | 19.5 | 20.0 |
| 15 | 19.0 | 19.5 | 20.0 | | |

Note: Under Ordinary Conditions Width of Channel is to be limited to 15.0 Feet. Extraordinary Conditions May Permit Channel Widths up to 20.0 Feet.

Compiled by R. S. Calkins, November, 1934

CHART SHOWING COMPUTATIONS FOR THE

TABLE OF WIDTHS FOR FLAT BOTTOM, SOD, TERRACE OUTLET CHANNELS

| Slope in Percent | S | S 1/2 | C | $C^3$ | R | 5R | K |
|---|---|---|---|---|---|---|---|
| 4 | 0.04 | 0.200 | 0.674 | 0.305 | 0.552 | 2.76 | 0.362 |
| 5 | 0.05 | 0.224 | 0.601 | 0.217 | 0.465 | 2.32 | 0.431 |
| 6 | 0.06 | 0.245 | 0.550 | 0.166 | 0.407 | 2.02 | 0.495 |
| 7 | 0.07 | 0.264 | 0.510 | 0.133 | 0.365 | 1.82 | 0.549 |
| 8 | 0.08 | 0.283 | 0.477 | 0.108 | 0.329 | 1.64 | 0.610 |
| 9 | 0.09 | 0.300 | 0.449 | 0.0901 | 0.300 | 1.50 | 0.667 |
| 10 | 0.10 | 0.316 | 0.427 | 0.0770 | 0.278 | 1.39 | 0.720 |
| 11 | 0.11 | 0.332 | 0.406 | 0.0670 | 0.259 | 1.29 | 0.775 |
| 12 | 0.12 | 0.346 | 0.389 | 0.0585 | 0.242 | 1.22 | 0.820 |
| 13 | 0.13 | 0.361 | 0.373 | 0.0518 | 0.228 | 1.14 | 0.876 |
| 14 | 0.14 | 0.374 | 0.360 | 0.0462 | 0.215 | 1.075 | 0.930 |
| 15 | 0.15 | 0.387 | 0.348 | 0.0420 | 0.205 | 1.025 | 0.975 |
| 16 | 0.16 | 0.400 | 0.337 | 0.0380 | 0.195 | 0.975 | 1.025 |
| 17 | 0.17 | 0.413 | 0.326 | 0.0345 | 0.186 | 0.930 | 1.075 |
| 18 | 0.18 | 0.424 | 0.318 | 0.0321 | 0.179 | 0.895 | 1.12 |
| 19 | 0.19 | 0.436 | 0.309 | 0.0295 | 0.172 | 0.860 | 1.16 |
| 20 | 0.20 | 0.447 | 0.301 | 0.0272 | 0.165 | 0.825 | 1.21 |
| 21 | 0.21 | 0.458 | 0.294 | 0.0253 | 0.159 | 0.795 | 1.26 |
| 22 | 0.22 | 0.469 | 0.288 | 0.0238 | 0.154 | 0.770 | 1.30 |
| 23 | 0.23 | 0.480 | 0.281 | 0.0222 | 0.149 | 0.745 | 1.34 |
| 24 | 0.24 | 0.490 | 0.275 | 0.0207 | 0.144 | 0.720 | 1.39 |
| 25 | 0.25 | 0.500 | 0.270 | 0.0197 | 0.140 | 0.700 | 1.43 |

Derivation:

$$V = \frac{1.486}{n} \quad R\ 2/3 \quad S\ 1/2$$

$$R = \left(\frac{vn}{1.486\ S\ 1/2}\right)\ 3/2$$

$$C = \frac{vn}{1.486\ S\ 1/2}$$

$$R = C\ 3/2$$

Assumption: R = Depth of Water

$Q = a\ v$ $\qquad$ $W = 5\ R$

$a = W\ R$ $\qquad$ $K = 1/v\ R$

$Q = W\ v\ R$ $\qquad$ $W = K\ Q$

Note: Widths of Channel are computed to the nearest half foot. Six feet is to be the minimum width of channel.

Computed by R. S. Calkins, November, 1934.

# TERRACE CONSTRUCTION WITH LARGE EQUIPMENT UNITS

by

John S. Glass
Chief Engineer
S. C. S. Project #11, Mankato, Kansas

The Soil Conservation Service Area, located in Kansas, and planned to be a demonstrational area for a considerable portion of Kansas and Southern Nebraska, is one of the original group of areas selected.

In conformance with the original idea this project includes the entire area of Limestone Creek and is limited to this watershed. Approximately 128,000 acres are farmed by some 629 farmers.

## SIZE OF FARM

We have cooperators who direct operation on areas varying from 10 acres to 1400 acres in size. However, the average size farm on the area is about 210 acres. Some 93,000 acres of the area is cultivated land. The rest of the 128,000 acres is in rough upland pasture, area occupied by the Limestone Creek itself, and farmstead areas.

## CROPS GROWN ON AREA

Row crops and wheat occupy a considerable portion of the cultivated area. The northern half of the project produces the greater acreage of corn, while wheat is the predominating crop in the south part of the project.

## MACHINE EQUIPMENT

These two crops being produced on a large scale basis, has naturally led to the adoption of large scale machinery for handling the crops. There probably is an average of less than three horses of workable age per quarter section of land. The tractor is the predominating unit of farm power. Multiple row crop equipment for planting and cultivating and power operated corn harvesting equipment is used almost universally. In the production of wheat, large drill units for seeding, and the entire small grain crop is harvested by means of the combine harvester-thresher.

## GENERAL TOPOGRAPHY

The Limestone Project from the point of topography presents some very wide extremes. Slopes varying from one or two percent to fifteen or twenty percent may be selected on many farms owned by our cooperators.

However, only a small acreage of twenty percent land is under cultivation. These steeper areas are for the most part confined to pasture land.

The major portion of the north half of this project area consists of a series of hill ranges that extend north and south. These ranges vary in length from half a mile to two or three miles. They are seldom very wide, a quarter to a half mile in width.

The general slope is to the south. The range of slope itself varying quite uniformly from nearly level to five or six percent. It is the east and west slopes of these ridges that have been most severely affected by sheet erosion. This evidence of severe damage by sheet erosion is of course the direct result of continued cultivation of areas carrying slopes varying from three to ten or twelve percent.

The southern portion of the project is more regular in contour. There are larger areas that might be termed as moderately undulating. Slopes of less than five and a half to six percent predominate, although some areas as steep or steeper than those mentioned above are frequently encountered, which add to the difficulties of the Planning Engineer, who makes the original recommendations with regard to engineering work to be done on the farm.

I have entered into this brief discussion of this Limestone Project Area, because the things that have been pointed out above, along with others to be enumerated later, furnish you with an idea of the sort of reasoning we followed in the selection of equipment for use on this project. These are at least some of the things that it would seem should determine the activities on any such undertaking.

## THE EXTENT OF OUR TERRACING PROGRAM

Without exception, there is some terracable area on every farm included in our area. When I say "terracable land", I refer to land that is either in bad condition from the standpoint of soil washing or is rapidly approaching such a condition, and to which terraces may be applied along with the Agronomic program, so as to make it a more farmable area. We terrace only land that when the terraces have been constructed, is in a more reliable condition to be farmed, following the crop plan procedure that has been developed for that land by our agronomists and the land owner.

Our program will include the terracing of approximately 35,000 acres. In order that this job may be fairly well completed it was plainly evident that we have adequate equipment to get the job done. We kept in mind all the time that eighteen months was the time to be allowed.

## DECISION ON EQUIPMENT

We certainly had only two choices. We might possibly handle the situation with a great many small outfits.

This possibility was given some consideration. Our reasoning followed along these lines: Supervision is an item of expense, with many scattered units in operation the heavier our overhead drom supervision costs; the particular terrace design we had decided upon was difficult to accomplish with light blade equipment; we use a somewhat wider spacing of terraces in conjunction with our contour farming program; we provide a terrace that was not a barrier in the field but one that could be readily farmed over with large equipment units, we used a large terrace cross-section; the farmers of our area were using large equipment units in their farm operations.

Our other choice was a few large outfits to get the job done. Certainly supervision costs would be reduced to a minimum by this procedure. The survey costs are no greater, and the engineering direction and checking are just as easily accomplished. The design of terrace we had in mind is very easily built with the elevating grader, and we recognized a draft horse size job that could not be handled by a shetland pony.

Our decision then, big equipment to do a big job.

Before entering abruptly into an explanation of the use of these large equipment units, which I presume will lead to considerable discussion, I wish to digress somewhat further and give you a brief word picture of our engineering procedure, and at the proper place introduce the equipment as we bring it into the activity.

## ENGINEERING PROCEDURE

Our planning engineer always has in mind, the complete agronomy program when making his recommendations. Our agronomists and engineers prefer to work a farm together. This is not always possible as we do not have enough engineers on the job making these plans. When the engineer works the farm alone he always has the Agronomists' report on that farm well in mind. These two men then get together and discuss the contribution that each has to offer for a complete erosion control program for the farm. Upon their agreement, the Engineer in charge of all surveys is given the plan and the surveying party makes the field surveys, not just laying out terrace lines but developing a plan for a terrace system for the areas to be worked. These men must avail themselves of every opportunity that presents itself, so that the job when built will be, not just another terraced field, but a real contribution to the capital assets of that particular farm enterprise.

Differences of opinion may develop between the planning engineer and the surveyor. These are always cleared before the final survey is ready for checking.

Three engineers must place the stamp of their approval on this final survey before it is turned over to the Construction Engineer.

The Chief Engineer, the Survey Engineer, and the Construction Engineer, pass on surveys together. Many transfers of ideas result from such checking, and the Construction Engineer has an opportunity to make suggestions, that from his view point of getting the job built are valuable and at the same time he gets the additional details that are readily passed on to the foreman directing operation of equipment on the job. Incidentally this check up gives the Chief Engineer an opportunity to keep in close touch with all engineering activities, that it would be difficult for him to accomplish in any other way.

## THE MACHINERY ENTERS THE PICTURE

The first machine operation is that of plowing out the stake line along which the terraces are built. This job is accomplished in a very satisfactory manner, using a Ford V-8 pick-up with trailer hitch to pull a single bottom lister. This is an important job, it must be done accurately and rapidly.

This plowing out is checked by the engineer who surveyed the particular field in question. Points that are given particular attention on this check are, the point of outlet into the outlet channel, portions of the line where special cuts or fills are to be made in rounding points of hills, or in crossing other irregularities in the contours of the area.

Our ripper comes into the field. This tool is of standard road machine design. We use it to cheapen the cost of moving earth with the equipment to follow, particularly the rotary scrapers with which fills along the terrace lines are built and the blade grader in outlet construction.

Outlet construction is the first step in our procedure. This is largely a blade operation, but is speeded up materially in most instances by ripping the channel prior to the blade work.

Our terrace survey engineers, avail themselves of every opportunity to eliminate crooks and sharp bends in terrace lines. This calls for cuts and fills to be made along terrace lines where ordinary procedure is to follow strictly the contour of the land. The use of the ripper makes it possible to accomplish this desirable portion of the terrace building operation in the most satisfactory manner. Earth material removed in a cut is used to make the adjacent nearby fill. Moving earth for those fills longitudinally along the terrace line, makes it possible to build these fills without borrowing top soil from over the intervening space between terraces, a very desirable feature in terrace construction from the standpoint of crop production immediately following the installation of a system of terraces. We consider the ripper, as we are using it with a 50 - Diesel tractor the most logical solution to our difficulties in handling particularly tough soil conditions, a most valuable addition to our list of field equipment. We believe this is the first time this tool has been given a place on the terracing equipment program.

Upon the completion of the ripper job on the outlet channels, these artificial water courses are excavated and shaped accurately using a twelve or fourteen foot blade drawn by a 50 - Diesel tractor. It is rather remarkable the skill that is shown by our blade operators. When they leave an outlet channel, only a minimum amount of hand labor is required in setting checks - sodding and preparing the channel for seeding for its protection.

While we have been engaged in the outlet channel other things of interest have been going on in this field. A 75 - Diesel tractor has come onto the job pulling a machine that had not been seen at the erosion control job prior to our adoption of it on the Kansas area. Here is the elevating grader. This is really an economical earth moving machine.

We have moved earth with this machine for a month at a time for as little as 1/3 of a cent per cubic yard put into the terrace ridge.

The only difference between this machine and the one you have seen on highway construction work, is the short delivery apron. The elevator itself is approximately fourteen feet long and the total cast from borrow pit to the terrace ridge about twenty feet. (This will vary slightly on different slopes.)

The lister furrow mentioned above is the guide line for the operation of the elevator. Our standard cross-section of terrace calls for nearly all of the terrace ridge to be built with the elevator. Since the soil is picked up with the elevator and placed directly where it is to remain in one operation (no pushing and shoving around), it is necessary that each move with this machine be well planned and executed. Good tractor drivers and elevator operators are able to accomplish this with uncanny accuracy.

The procedure is as follows: The first trip along the terrace line the outfit is driven so as to deliver the furrow slice 4 1/2 feet over the guide line, the lister furrow. On the return trip the cut is delivered in the same relative position. The second, third, fourth, fifth and sixth rounds, as may be required, are cut and delivered to give the required yardage and shape to the ridge that is desired in so far as it is possible to accomplish it with the elevator.

When the job has proceeded this far we find we have, a borrow pit both above and below the rough ridge of earth that has been placed on the guide line. The high spots that are usually a troublesome part of blade terrace construction have been eliminated ahead of the elevator work by use of the ripper and tumble-bug, or rotary scraper, and we have a uniformly high terrace ridge across all low spots in the field, because all the fills have been made prior to putting the elevator on the job.

All that remains to be done to finish our terrace is to shape the water channel and eliminate the borrow pit on the lower side of the terrace ridge.

These two jobs are accomplished with the fourteen foot blade grader and a unit of heavy tillage discs.

The blade work is done in two rounds. The first round, pushes an added yardage of earth to the toe of the elevator ridge, adding base width to the ridge and helping to shape the terrace cross-section. The second round has two jobs to perform. The up slope borrow pit is partially filled, by back sloping the slope into the terrace channel. In this operation we partially cover the exposed subsoil of the terrace channel with top soil material, and lengthen, thereby decreasing the slope from the original ground level into the channel of the terrace. The lower borrow pit is treated in a slightly different manner. Some top soil is cut into it, and at the same time the down grade shoulder of the borrow pit is eliminated so that this borrow pit will carry no water.

One more operation and our terrace is complete, ready for the final check by the survey engineer.

Three heavy tillage discs handled by a 50 - Diesel are used to work down and accomplish the final shaping of the terrace cross-section.

These discs are multiple hitched in the following manner. A wide spread hitch unit is used, the discs placed so that an offset double throw disc is run on the terrace ridge slope. A regular tandem disc cuts up the bottom of our terrace channel, and the area over which all the machinery has traveled in building the terrace ridge, while the third disc, another offset double throw disc, cuts the back slope into the elevator borrow pit.

We now have the completed terrace ready to be turned over to the farmer, who will put into practice the agronomy program for the area.

If I were to hesitate now, many of you would begin with questions about the cost of this job. Then if I answered without explanations you would either leave here doubting that it could be done or commending yourselves on your own procedure. To eliminate either of the above from happening I'll give you cost data with explanations and let you draw your own conclusions the same as I have.

We complete the job. By that statement I mean we terrace all of a given slope that needs to be terraced, from the top to the bottom when that area is to be handled in the regular crop rotation. We build interception ditches when the cultivated area lays on a slope with pasture or hay land above it. We fill all gullies that appear in the field so that they may be crossed readily in the contour farming operations. We complete all outlet channels, ready for the hand labor of installing the checks, sod or seeding of the channels. We leave the terraces so that they are ready for cultivation, when they are given the same seed bed preparation that is necessary to prepare the field for crop.

On this basis 803 miles of terrace plus 12.0 miles of interception ditch and 60 miles of outlet channels have cost us $85.78 per mile of structure. On our Area each mile of terrace benefits approximately 20 acres of land, hence the cost per acre benefited up to December 1st has been $4.32.

Now let us see how this money was spent.

| | | | |
|---|---|---|---|
| 1. | Equipment purchased outright | | $17,485.95 |
| 2. | Equipment purchased by rental | | 12,615.45 |
| 3. | Rental for county, township, and private equipment | | 11,397.96 |
| 4. | Fuel oil and grease | | 5,650.72 |
| 5. | Repairs and blacksmithing | | 4,631.67 |
| 6. | Labor | | 21,264.47 |
| 7. | Transportation - | Government Cars | 1,239.77 |
| | | Private Cars | 774.47 |
| | | Total | 75,060.64 |

It would be misleading to assume that future terrace construction will cost us $85,78 per mile since the above figures include $30,101.40 for the purchase of equipment, and this figure is approximately 60 per cent of the total value of all construction equipment that we now have on the job. In addition we spent $11,397.96 for the rental of township, county, and private equipment. This one experience convinced us that it is much more economical to own equipment than to rent the type of equipment available from such sources.

Our costs have not been uniform due to the fact that we have been changing methods of construction and the type of equipment used as the work progressed. During the month of November we operated what we believe to be our most efficient unit and were building a large cross-section terrace which contained approximately a cu. yard of earth per lineal foot.

These costs based on a five weeks period and broken down into their component parts are as follows:

COST OF CONSTRUCTING TERRACES
(FIVE WEEK'S AVERAGE)

1. Core - Elevator Job

   1,146 feet constructed per hour.
   4.61 hours per mile of terrace.
   $4.24 per hour of operation.

   Core cost per mile of terrace (6 rounds) $19.56

2. Blade Work on Terrace

   1,938 feet bladed per hour.
   2.72 hours per mile of terrace.
   $2.94 cost per hour of operation.

   Blading cost per mile of terrace 7.81

3. Finishing Work on Terraces

   2,425 feet finished per hour.
   2.18 hours per mile.

   Finishing Cost per mile of terrace 6.18

   Cost per mile Total $33.55

4. Fresno and Ripper

   8.4 hours per mile of terrace.
   $2.84 cost per hour of operation.

   Fresno and Ripper cost per mile of terrace $23.85

| | | |
|---|---|---|
| 5. | Transportation of men - cost per mile of terrace | $ 5.30 |
| 6. | Moving machinery - cost per mile of terrace | $ 2.98 |
| 7. | Greasing cost per mile of terrace | $ 2.37 |
| 8. | Blading gullies - cost per mile of terrace | $ 1.07 |
| 9. | Blading Outlet Channels - Average 400 feet per mile of terrace (costs 1.95¢ per foot) | $ 4.78 |
| | Grand Total | $73.90 |
| 10. | Interception Ditch cost per mile | $74.20 |

I desire to call your attention to one of the above items which on many areas are not considered a necessary function of the Soil Erosion Service. The largest single item of expense is that of $23.85 per mile which is charged to the Fresno and Ripper. We cross many gullies with our terraces and the necessary fills at these points in addition to the fresno work in extending the terraces into the outlet channels requires the moving of large quantities of earth.

The greater part of this work could be considered gully control and it is our contention that an earth dam with a terrace for a spillway is the cheapest and best form of gully control in a cultivated field in most instances.

Further explanation of the various units in the above costs will be given in the round table discussion to follow this paper.

Exhibits - Slides to be used with the descriptive part of this discussion.

1. The lister furrow.
2. The ripper - in action.
3. The blades and a finished outlet.
4. Tumble-bug at work without ripper.
5. Tumble-bug job following ripper.
6. The elevator, round one.
7. The elevator terrace core.
8. Blade, adding to toe.
9. Blade backsloping.
10. The disc.
11. Drawing cross-section ideal to aim at.

ESTIMATED HOURLY CHARGE FOR EQUIPMENT

| | 48" Elevator & 75 | 42" Elevator & 50 | Blade & Tractor | Fresno-Tractor-Ripper or Disc |
|---|---|---|---|---|
| Mechanic | .30 | .30 | .15 | .15 |
| Operators | 1.20 | 1.20 | 1.20 | 1.20 |
| Grease No. 53 | .16 | .16 | .12 | .12 |
| Oil | .10 | .09 | .04 | .04 |
| Rental Depreciation | 1.00 | .70 | .61 | .51 |
| Fuel 4 at 5.5 5.5 at 6 .147 | .33 | .22 | 3 Gal .16 | 3 Gal .16 |
| Gas 2 1/2 Gals. | .35 | .35 | .01 | .01 |
| Foreman | .30 | .30 | .15 | .15 |
| Repairs | .50 | .50 | .50 | .50 |
| Total | 4.24 | 3.82 | 2.94 | 2.84 |
| | | | | |
| | | | | |
| Supervision | .60 | .60 | .30 | .30 |
| Labor | 1.20 | 1.20 | 1.20 | 1.20 |
| Material | 1.44 | 1.32 | .83 | .83 |
| Depreciation | 1.00 | .70 | .61 | .51 |
| Total | 4.24 | 3.82 | 2.94 | 2.84 |

# ENGINEERING PHASES ON THE NAVAJO PROJECT

by

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## INTRODUCTION

Project Number 10 of the Soil Conservation Service, called "Navajo Project", covers the Navajo Reservation in northeastern Arizona, northwestern New Mexico and southern Utah. The land is entirely Federally controlled and the project is not concerned with the usual land ownership problems. On the other hand it is concerned with many unique problems which arise from dealing with a primitive nation whose language, customs and habits of thought are different from our own.

The purpose of this paper is to discuss these problems, especially in relation to the work of the Engineering Division. For a perfect understanding of the work involved it will first be necessary to give a brief description of the region under treatment, thus indicating in general the problem and its solution. The main discussion will cover those engineering phases involved in the present work on our so-called "Demonstration Areas" within the project.

## DESCRIPTION OF AREA.

### GENERAL.

The Navajo Reservation comprises approximately 17,000,000 acres of land, bounded on the south by the Little Colorado and Puerco Rivers, on the north by the San Juan River on the east by the 108th meridian, and on the west by the Little Colorado and Colorado Rivers.

The average elevation of this region is close to 5,500 feet varying from 2,800 feet to 10,400 feet.

The annual precipitation varies from over 15 inches to less than 5 inches with a probable average of 9 inches. The seasonal distribution is poor with 40% occurring during the months of July, August and September and less than 12% of the total during April, May and June. The storms, in the months of greatest rainfall, are of the thunder shower type with duration usually of less than one hour.

A prevailing wind from the southwest plays an important role in changing the land conditions over the Reservation.

Two types of soil are to be found on the Reservation, namely, residual and transported. The latter type predominates because of the nature of the precipitation, the scantiness of vegetation and strong prevailing winds.

### VEGETATIVE CONDITIONS.

The seasonal distribution of precipitation, the temperature, and type of soil all tend towards a vegetation which is adaptable to range use

or leads to the raising of livestock as the principal industry. While grazing under proper control is not necessarily harmful to the vegetation cover, yet under the conditions as found today and probably prevalent since 1890, the range is greatly overstocked. Excessive and uncontrolled grazing have resulted in severe vegetation depletion.

As the period of least rainfall from April to June is also the growing season for most crops it is apparent that productive agriculture is quite a problem. Proper farming under flood irrigation appears to be the type most likely to succeed on any large scale over the Reservation.

Not over 5% of the land in the Reservation is covered with saw timber species. Possibly 20% of the area is covered with pinon and juniper but due to overgrazing, reproduction is lacking over possibly 90% of this area.

EROSION CONDITIONS.

Except for the timbered areas in the higher altitudes and small protected tracts, erosion is generally evident in some form over the entire Reservation. While sheet erosion is present, advanced gully erosion, as indicated by thousands of miles of arroyos, ranging from 10 to 100 feet deep, assumes major significance. Channel beds in many sections are rapidly cutting deeper, and present intermittent gullies promise soon to form one continuous arroyo unless controlled. In other sections the bed of the stream is stabilized but broad valleys are being threatened through lateral cutting. Soil swept away is being spread over potential farm land or deposited in reservoirs along the rivers.

Wind erosion is also quite general and many slopes have been swept clear of all their soil cover, leaving bare the roots of shrubs and trees. This same blow sand is burying other vegetation and the sand dunes are constantly on the move.

As indicated, the main cause of erosion throughout this region is the destruction of the vegetative cover by overgrazing. Highways, wagon roads, stock trails and improper cultivation are also contributing factors.

It must be understood that the term "erosion" as used herein means an accelerated process due to human action, rather than the gradual carving of the landscape by geologic and climatic influences.

THE PROBLEM AND ITS SOLUTION

From the above description it may be noted that the condition of the land in the Reservation is very serious. The Navajo tribe is increasing and today approximately 46,000 people are attempting to exist on this land with livestock as the main industry. As it is impossible to consider moving the Indians to new lands, the problem facing the Soil Conservation Service is mainly the protection and preservation of the remaining valuable land.

Proper land use methods designed to protect and increase in density the vegetative cover appear to be the only logical solution. This statement

would first seem to place the work in the hands of the range examiners and foresters rather than in those of the engineers, except as roads and trails cause erosion; but the term "vegetative cover" is in a large sense an engineering term as its purpose is to protect the underlying soil from the action of the elements in much the same manner as an engineer uses asphalt covering to protect the road bed from the erosive action of the wheels of traffic. It is quite true that possibly forty or fifty years ago the solution of the problem would have concerned only the range examiners and foresters but today, with erosion in an advanced stage, these Divisions must necessarily call to their aid the engineers, soil experts and agronomists.

As all phases of erosion control are involved in the solution of the problem each Division has its special work. Proper range control with the number of livestock reduced to the estimated carrying capacity is the objective of the Range Management Division. This same control will permit reproduction in the timbered areas. The agronomist is interested in the reseeding of certain areas, and proper farming methods in order to increase the yield from agricultural land and to protect the same from erosion. The soil expert determines the proper land use for the various types of soil.

The engineer must have a general understanding of all the above phases in order better to correlate them with whatever engineering work is required to round out the program. For example it would be useless to attempt the building of a number of structures to hasten revegetation of the land unless it were possible to secure proper grazing control to protect the vegetation. It also would be useless to build structures in an area where the soil is not suitable either for their construction or for revegetation.

Many of the engineering phases involved, such as map compilation and detailed surveys to supplement aerial maps, are generally similar to those encountered on other projects. An attempt has been made, however, to hold this discussion to those more or less peculiar to this one Project. The main portion of the present engineering work is confined to certain selected areas where methods of artificial control are being demonstrated to the Navajos.

## DEMONSTRATION AREAS

The need, purpose and results obtained from engineering structures, range control, and proper farming methods must be clearly demonstrated to the Navajos before they may be expected to accept the final plans as applied to their 17,000,000 acres of land.

This demonstration may best be accomplished through establishing a number of selected areas, well distributed over the Reservation, upon which all phases of proper land use may be practiced. At the present time approximately ten of these areas, varying in size from eight square miles to 67 square miles, are under treatment. The majority of these are of the general demonstration type but one or two may be termed "Cooperative Areas" where those Navajos receiving direct benefits are expected to contribute, without pay, to the work.

Each of these areas is covered under an agreement whereby the inhabitants permit the area to be fenced and placed under the control of the Soil Conservation Service for the period of the agreement. This allows regulation of grazing and farming methods.

Before discussing in detail the engineering work involved on these areas it is necessary to illustrate the general conditions by a description of a typical cross section of the region. This would show a fairly flat slope at the divide, a steep slope from the break to the valley floor, and a slight fall from there to the main arroyo. The areas at the divide and the valley floor at one time contributed the best range land on the Reservation but are now cut up badly by gullies fingering out from the main arroyo. The steep slope often consists of rock, swept bare by the forces of wind and water. The main drainage often consists of intermittent gullies which tend to form one continuous arroyo unless controlled.

## ENGINEERING PHASES OF WORK ON THE AREAS

The engineer is by training equipped to supervise engineering construction and with even a limited knowledge of agronomy, forestry and soils, he is the logical man to place in supervision of these areas. As such, he is called Project Engineer and may have charge of one, two or three areas. Under him and in direct supervision of such area is a Project Manager who has complete charge of construction.

The engineer is first concerned with a map of the demonstration area. The entire Reservation has been covered with an aerial survey and it was hoped that through the use of this and small supplemental surveys a suitable map could be prepared of the individual areas. There has been a delay, however, in securing the aerial mosaics covering most of the demonstration areas and it has been necessary to proceed in many instances with reconnaissance maps only. In the future, however, a map will be prepared which indicates main drainages, cultural features and well defined ridges and breaks of slopes. A contour map is made only where required for a special structure layout.

The engineer in charge of the area is expected to correlate the plans and recommendations of each Division into one "Area Working Plan." The area is divided into sub-areas, each consisting of one or more complete drainages and the Working Plan deals with them as units.

Since the proper sequence of all erosion control work should be from the upper limits of the watershed down the drainage, work done on the gentle slopes at the divide really serves the dual purpose of aiding the return of vegetation on those slopes as well as protecting the land below from water and silt. The nature of the required treatment is that which will detain or spread the flow of water. This is accomplished by a number of impervious dikes or contour furrows well distributed over the area, giving the appearance of several small reservoirs. As the slope steepens (up to 5 or 6%) these impervious dikes are replaced with weepers or spreaders, on the contour, the purpose of which is to retard runoff by causing a slow, even, spill or seepage, and thus eliminate the danger of concentration. Across the gullies in all cases impervious diversion dams should be built.

The earth dike or dam is usually the most economical but in certain sections of the country, with a low rate of precipitation, careful consideration should be given to the disturbing of a vegetative cover which is difficult to replace. Low brush or rock dikes also make ideal detention or spreading works. An economical dike for temporary purposes is one constructed of burlap sacks filled with soil. The woven wire fence backed with brush or burlap also has been used to detain and spread the water with great success.

As a rule, the steepest slopes are left untreated as more harm may result than good. An exception is made in the case of active gullies where a few low check dams may control further cutting.

The valley floor presents many major problems to the Engineering Division since it is here in particular that the agronomist and range men need aid. At the present time practically all benefits from precipitation are lost, as the runoff is rapidly carried away through a system of gullies. Artificial control is required in order to take the water out of the arroyos and spread it slowly over the land. This requires diversion dams, dikes and spreaders. The type of dam depends mainly on the watershed, since a small runoff may be diverted entirely, whereas a larger runoff calls for a center spill type of dam designed to divert only a portion of the flow. The materials of construction depend on the use of the structure as well as availability of material. Earth, rock, brush, concrete or masonry, wire and rock, wire and brush, timber, and treated or untreated sacks filled with earth or cement indicate the wide variety of materials used in the common types of dams.

Frequently the engineer is inclined to overlook the importance of the drainage area above a structure, especially if it happens to be a small dam. He is likely also to use the present gully and high water marks as a guide without realizing that at times the banks have been overtopped. Methods of correct design can take into account only the area of watershed and its nature. In those sections of the country where the relation of runoff, precipitation, slope and vegetation has been determined this is an easy matter but at present this region is unfortunate in lacking such a predetermined relation of factors. Until it is determined, common sense alone must be the guide in design of structures. Other precautions which must be taken in the design of these dams, especially those made of earth, are core walls, deep cutoffs and sloping of the banks preliminary to construction.

After diversion from the gully the water must be spread over as large an area as possible in order to delay its return to the channel and to furnish a maximum of irrigation for hastening revegetation. Spreader structures are built either on the contour or a slight grade depending on their type or the amount of runoff. The impervious dike is used to carry water away from the banks where it may be spread by means of low rock or brush dikes, low woven wire fences backed with burlap or brush, or low sack dikes with small openings for seepage. These spreaders should be staggered and spaced so that the water has no chance to concentrate and cause gullies.

The points of diversion should be carefully selected, remembering that silt as well as water will be spread. If revegetation is to be aided this depth of silt must not be excessive.

Another problem confronting the engineer and perhaps the paramount one in this country is that of controlling active head and lateral gully erosion. It is hopeless to expect vegetation, even under perfect grazing control, to keep pace with this type of erosion until it has had a chance to attain its growth. The engineer therefore must provide some artificial means of control.

The type of this control depends on many factors, including drainage area, soil, vegetation and topography; but in a general way it may be divided into three classes, diversion, centrally built drop structures, or sloping of banks.

In this country the best method, where it can be used, has been the diversion of runoff water by means of an impervious dike just above the point of active erosion and the spreading of the water before it returns to the arroyo. By diverting the flow, the arroyo has a chance to heal and revegetate; and through spreading, revegetation is hastened. This method, however, is only possible where the runoff is not excessive and the valley broad enough for spreading. Small local drainages are often responsible for lateral erosion and it has been found possible to stop the same by placing a low level dike on the bank of the arroyo which provides a slow even spill and prevents concentration.

Where the topography does not permit spreading or where the runoff is too great, the water must be dropped into the arroyo through one central structure and thus alleviate further head erosion. Depending on the permanency required, these structures may be built of concrete, masonry, sacks filled with cement and sand, wire and rock, asphalt emulsion and aggregate, timber, wire and brush, and brush.

Experiments are being made on these areas to determine the actual value of artificial sloping of the banks of an arroyo, followed by revegetation, in this country with a poor seasonal distribution of rainfall. Various slopes as well as different types of vegetation and methods of planting will be compared with untreated slopes in adjacent arroyos in order to determine the value of the treatment.

The tracts of land selected by the Agronomy Division for demonstration of proper farming under flood irrigation, are in general located in the valley floor. The design and construction of the necessary training dikes, emergency spillways and diversion dams are the concern of the Engineering Division.

The main arroyo offers a difficult problem to the engineer. Careful study of its characteristics is necessary before attempting treatment. As a rule, this treatment should not be undertaken until all drainages above have been placed under control. The arroyos may be divided into two classes, those which are continuing to cut deeper and those which are stabilized as to bed but which are cutting laterally.

In the first class, low check dams are necessary to stop further cutting and to provide silt beds for planting. These cross structures must be carefully designed to take the total discharge of the channel.

In the latter class, trees and shrubs are planted along the foot of the bank to control side cutting. These must be protected by artificial structures

until they obtain their growth. The required structures consist of jetties, dikes and fences.

With few exceptions it may be noted that all structures mentioned in this discussion may be classed as temporary, in that they are to act only until such a time as vegetation replaces them. The Agronomy Division has charge of the seeding of structures which are to act as centers for future vegetative spread.

The matter of records is very important in order that relative costs of different sub-areas or units may be compared and results noted. These same records also indicate the cost of a few typical structures for future estimating.

The photograph provides an ideal record and, stations have been established on all areas from which views of the work may be taken at certain intervals of time. These stations are marked in the field and located on the maps.

## MISCELLANEOUS ENGINEERING PHASES

The concentration of runoff caused by highways, wagon roads and stock trails, has caused much of the erosion found on the Reservation. The treatment of existing roads, used and discarded, as well as of future roads, is a necessary part of the engineer's problem. This treatment in general consists of proper drainage and spreading of water so as to stop undue concentration. Policies governing this phase are being drawn up and will be given to all road building agencies on the Reservation.

Another phase is that of engineering training. The range examiner, soil expert, and agronomist each has trainees working with him and on the areas the engineer and manager act as training leaders and foremen. The Engineering Division has lately undertaken the instruction of a small group of Navajos in elementary engineering, such as surveys, map making and layout of erosion control structures.

The various engineering phases just discussed will be applied to the Reservation as a whole when final treatment plans are undertaken. This will follow the completion of the grazing and soil surveys of the Reservation.

## CONCLUSION.

In conclusion a few of the rather perplexing questions which require answering on this Project are stated in the hope that a discussion of the same may be started.

1. What is the most logical method of estimating the economical concentration of engineering structures in range country?

2. To what degree should the use of large machinery be permitted in engineering work on the Reservation?

3. To what extent should the need for employment affect economical erosion control work?

# RELATION OF THE EMERGENCY CONSERVATION WORK CAMPS TO THE SOIL CONSERVATION SERVICE

by

J. G. Lindley
Supervising Engineer, E. C. W.

The evolution of the Soil Conservation Service has been adequately described in professional papers, Congressional speeches and in various published articles both in technical publications and in the newspapers. However, a brief summation of the pertinent facts are probably in order.

For a number of years men engaged in agricultural pursuits, the dirt farmer, the government expert, the engineer, the extension agent, had their attention irrevocably directed toward the growing menace of accelerated soil erosion. The exceptional farmers and cattlemen recognizing the existence of the problem tried to solve it by varied expedients. Conditions were acknowledged to be bad; but, on the whole, little or nothing was done about it.

The few people who would not be quiet about it, who insisted that corrective measures had to be applied and existing causes removed, were regarded as cranks or publicity seekers, and had a hard time making themselves heard amidst noise and confusion of a prosperous nation going about its multifarious business. With the depression, and the consequent paralysis of a good portion of that business, many men had more time to listen to cranks, time to ponder, and time to awaken. The "New Deal" has never been too busy to answer questions; and, if it doesn't know the answer, to investigate and analyze causes and effects until the answer becomes apparent. The President of the United States and the Secretary of the Interior both harkened to the still, small voice crying against the National Menace.

After long years of travail, there was instituted in the Department of the Interior, the Soil Conservation Service, clothed with the proper authority and invested with sufficient funds to set up in various strategically located areas important and impressive demonstrational erosion control projects.

The C.W.A. with its need for work projects acted as the starting lever on many of these projects. Bearing in mind the necessarily temporary character of the C.W.A. employment, those directing the affairs of the new service turned to the Emergency Conservation Work, the great new venture in social relief inaugurated in the spring of 1932.

The allocation of twenty-two ECW camps to the Soil Conservation Service for the third camp period, April 1, 1934 - September 30, 1934, has been of great value in forwarding this work. The twenty-two camps were located on fourteen of the project areas, assignment being made of one or more camps to an area as conditions warranted. Twelve of the 172 new 200-man camps established in the drought stricken area of the country during the summer of 1934 were allocated to this service. At the end of the third camp period, the work accomplished in the camps was used as a justification of their continuance during the fourth camp period. This request met with the approval of the Director, Mr. Robert Fechner, who also approved the assignment of seventeen additional camps to this service for the winter period, so that at the present writing there are, in all, 51 camps being operated by this service.

The work of these camps are largely restricted to gully control. Gullies occur in every state and outlying possession of this Union. They are caused, obviously, by water flowing at a velocity sufficient to move and carry away soil particles. They are often started by artificial means, - plow furrows, paths and trails, wheel ruts, and almost invariably by the farm yard run-off. The longer the stream the greater the capacity for erosion. Nature's own methods of checking some of her own processes are the ones that man has to make use of. First comes the establishment of a new and less sloping grade for the stream bed, thereby lessening the velocity and to a large degree the cutting and carrying power of the stream. Second is the fixing of the surface of this new grade line by means of a vegetative cover, with its surface litter and obstructions to flow and its sub-surface network of roots.

This new grade line can be obtained by a combination of check dams, pits, mounds, ditches, contour furrows, dikes, application of natural physical and structural landscape features, planting, withdrawal from cultivation of certain lands and innumerable related objects and undertakings. Probably check dams of varying sizes will be used more than any other structures.

With the necessity of putting men to work as quickly as possible on C.W.A. and related projects the actual work often got ahead of the program. Engineering, of necessity, has lagged a little behind accomplishment. This is exactly the reverse of the ideal condition and an effort is now being made to correlate the various engineering features that have been used in the construction of check dams and to make the work in camps easier for foremen and men by establishing certain standards for the varying types of structures that come under the head of check dams.

There are included in the work projects a wide range of soils, agricultural belts, geographical locations and topographical conditions; the Piedmont regions of the Southeast, the overgrazed alluvial valleys of the Southwest, the Wheat Belt of the Northwest, the glaciated soils of the upper Mississippi Valley, the Black Belt of Texas and the windblown soils of the Middle West. A variety of control measures are being applied, combining engineering, forestry, cropping and land-planning practices, based on the variations of soil, topography, rainfall, types of agriculture and related conditions.

In using the CCC men on private land bear in mind that the work is not to be done for the benefit of the owner of that land but for the benefit of the community. The men are not to be used even on gully control on the land of a single individual unless the gullies on that land form a menace to the community.

In addition to the work which a landowner can do on his own land there is a large amount of work that should be done that he is unable to do, that he is usually not competent to line up. It is work of this nature, and there is plenty of it in a properly coordinated program, that will enable our staff and camp engineers to keep busy laying out work for the enrollees.

Before closing I wish to commend as especially helpful the handbooks of erosion control issued severally by the Illinois project and the Ohio project, and with which I believe all present are familiar. It is to be hoped that other areas will emulate these examples, and from the data so assembled there may be worked out a handbook of erosion control that will be of general application.

In order to provoke a little discussion I wish to show a few slides to illustrate the work now being done by enrollees in the various camps.

# PRACTICAL PHOTOGRAMMETRY

by

Edward A. Schuch
Photogrammetrist in Charge, S. C. S.

In order to have a clearer understanding of Photogrammetry it is necessary to have a knowledge of the early history of mapping.

Probably the first of the more important discoveries that led to the present method of mapping development was the discovery of the principal of magnetism by the Chinese. At first the magnet or lode stone was surrounded by superstition but later its practical value was realized.

About this time civilized people began roaming from place to place and with the aid of the compass which was the result of discovery of magnetism the mariners were able to take longer voyages and sail beyond the sight of land with the assurance that they could return with the help of the compass.

As navigation and travel increased and regular routes of travel were established there became a necessity of a graphic record of these travels. This led to the compiling of the earlier form of maps which were merely panometric drawings of the places visited.

Most of these early maps were masterpieces of art but until after the development of astronomy no attempt was made to orient the data on the map in reference to its position on the earth's surface.

In the following centuries slow progress was made in the science of charting. Directly after the invention of the camera the Italians realized the possibilities of the use of photographs in connection with mapping and photographic plates were exposed from both ends of a measured base line. These photographs were so oriented that the same images appeared on both pictures and formed what is known as a stereoscopic pair.

A crude map was made from these pictures by a graphical system of point by point plotting, having known the coordinates of the exposure stations and the focal length of the lens. These early experiments led to the development of the stereoscope by the Germans who have always been leaders in the physics of light.

During the World War the airplane and camera were rapidly perfected naturally leading to the development of aerial photography.

Mosaics were compiled from the first aerial photographs for use in military tactical studies. These emergency developments have gradually led to the present methods of photogrammetric mapping.

The European countries have developed several stereoscopic plotting devices which work on geometrical and optical principals. These machines are very complicated and expensive which prohibits their use for mapping large areas of relatively small value such as we have in America.

The pioneers of photogrammetry in the United States have developed the radial line system of planimetric mapping from aerial photographs which is a cheaper and more accurate method of mapping than the ground methods previously used.

## Contact Prints

Two types of aerial contact prints are used by the Soil Conservation Service--they are the four-lens and the single-lens. Both of these types are particularly adapted to mosaic and planometric mapping.

The single-lens negatives are taken with a camera having not less than an 8 inch focal length and an image area of not less than 61 square inches. The four-lens prints are made from four negatives exposed at the same instant, each exposure being taken in a different quadrant. These exposures are taken on an angle and later transformed into a single horizontal negative.

The flight lines are either east and west or north and south, whichever direction is best fitted to our needs.

Special attention is given to keep the flight lines as straight as possible. Flight lines varying more than five degrees from the true flight direction are considered undesirable for aerial mapping. The prints must also be taken while the camera is held in as nearly a horizontal plane as possible, and any print with a tilt of more than $2^{\circ}$ is considered too great for accurate mapping. It is also essential that each picture overlaps the adjacent picture 55% and overlaps the adjoining strip by 30%. With this required overlap, a margin around each picture and a strip through the center is covered by three different pictures and the entire area by at least two pictures, giving stereoscopic vision over the entire area.

## Enlarged Contact Prints

Enlargements from the aerial negatives at a scale of 1 inch equals 500 feet are used as base sheets for the field assembly of various soil, slope and erosion data. The reproduction scale is determined by scaling the distance between section lines in a sectionized country and in an unsectionized country the ratio is determined by the mean scale of the flight line.

The enlargement, being a reproduction, contains the same degree of displacement and distortion as the contact print which is at a maximum at the extreme edges of the negative. Particular care is taken in these reproductions to obtain the maximum amount of definition. Prints that are not clear are rejected and the contractor is required to

furnish additional prints that are satisfactory. These enlargements are sufficiently accurate for most purposes required of a field map. They possess most of the property lines, the woodland areas, scattered woodland areas, houses, and the crooks and turns of the streams. By using the enlargements along with the smaller contact prints and with the aid of the stereoscope, accurate locations of gullies only a few feet deep can be determined. The difference of cultivations in a single field can be identified, thereby eliminating a large amount of work that ordinarily would be required by field measurements.

## The Uncontrolled Mosaic

The uncontrolled mosaic which has been used to some extent is rapidly losing its popularity due to the inaccuracy with which it is made.

These mosacis are made by pasting together small portions of the contact prints, which when assembled, appear as one large picture. As no control is used to tie the pictures together, it is necessary to reduce and enlarge certain portions of the various contact prints to make the images match between pictures.

The uncontrolled mosaic is a bad piece of ingenuity and should not be used in connection with engineering work, but should be superseded by the enlarged contact prints.

## Planometric Maps

An aerial planometric map is a line map made from aerial photographs. This map usually contains all details such as roads, trails, houses, barns, rivers, creeks, gullies, sand bars, woodlands, lone trees, pronounced river banks, field outlines, section lines, property lines, mountain ridges, peaks, bridges, swamps and all other details visible to the eye. In fact, the planometric map is rapidly taking the place of similar maps made by transit stadia and plane table methods. During the past year, approximately 60,000 square miles of the United States was covered by aerial planometric maps.

The stereoscope is used in nearly every step of planometric mapping. By its use, an object such as a particular tree top in a dense woods can be accurately distinguished and plotted. Houses and bridges that would be overlooked by the naked eye can be readily distinguished, and the smallest drain can be plotted from its source of origin. The cost of such a planometric map including field control, cost of pictures and map compilation is approximately 1 1/4 cents per acre.

The accuracy of a planometric map depends on the accuracy of the field survey that controls it. A transit survey is run along two edges of the area that is to be mapped and three points are identified on each picture that the control line crossed. If the flight lines are run north and south, the transit control is run east and west along both ends of the flight line.

After the control is run, geographic positions are computed for the picture ties and these positions are plotted on the polycomic projection which is laid out on a specially prepared celluloid. This celluloid is practically non-inflammable and is buffed on one side to take ink. The scale of the map does not have to be compiled at the same scale as that of the pictures, and it has been decided to make our planometric maps to the scale of 4 inches equals 1 mile.

For most aerial surveys, one lineal mile of transit control is sufficient to control eight square miles of mapping. This holds true with the exception of very irregular tracts that require more control.

From these prints that are definitely fixed by field control a net-work of radial triangulation is extended through the entire project until every print is oriented by nine or more points.

The principal point or geometric center of the picture is recorded on the photograph, either by a mark on the center of the picture or by marginal data. This principal point on an untilted picture is the plumb point beneath the camera at the instant of exposure is its true center. By the use of the stereoscope this principal point is transferred to the two adjoining photographs and so on through the flight. The line connecting these points is known as the azimuth line and corresponds to the azimuth line of a transit survey. After this is completed, three points are picked on each side of the principal point and transferred by the stereoscope to the adjoining pictures. These same points now appear on three separate pictures, except the outside row of the end pictures where the points appear on only two pictures. These points are called radial control points. The next flight is worked through in the same manner except on the edge that overlaps the flight previously plotted, along this edge the points are transferred from the first flight so that now these points appear on six different pictures. This radial control net is continued throughout the remainder of the flights until all the points that fall within the overlap of another picture are common to each other.

After the radial control is completed, a celluloid templet is placed over the contact print and radial lines are drawn from the principal point through the azimuth and radial points. A templet is made for each contact print.

After the templets are completed they are ready to be laid into their true position on the base map. Each templet must now be considered as a plane table sheet with the alidade at the geometric center, and each radial control point a triangulation point cut in by the alidade. By placing the first templet in such a position that the radial lines to our three field control points pass through the plotted position on the sheet the first templet is accurately located. Then, by placing the azimuth line of the second templet over the azimuth line of the first templet the second templet is moved along this azimuth line until the radial line to the field control point passes through the plotted position on the base map. The templets are all laid in this manner until all the points are three and up to six point intersections. As all

distortion on a photograph is radial from its center, and our radial control is based entirely on angles, these intersections are the true positions of the points on the pictures. This network is now turned over and the intersections recorded on the back of the celluloid base sheet with the drop bow-pen. The center of the picture is also recorded and numbered.

The drainage and culture is then studied under the stereoscope, and all the topography that is to become a part of the planometric map is inked on the contact print.

This data is now ready to transfer to the base sheet and by the aid of a projector the images are projected on to the base map that has been recently designed using the radial control points to place the topography in its true horizontal position. When the radial control points of the projected image coincide with the control points on our base map, the topography is traced onto the map at the scale of 4 inches equals 1 mile. The scale of the picture from which the topography is transferred is approximately 1":1666'.

After the topography is traced on the base sheet the radial control points are washed off the back of the celluloid sheet. The center of the picture and its number is recorded on the front of the sheet and becomes a part of the map.

In rough countries a great deal more radial control is needed due to the distortion caused from relief and it is necessary to pick radial control points on all the peaks, divides and a series of points down the canyons. This gives us the true positions of the mountain chains and the canyons that separate them. As many as 50 to 60 extra points are needed to a print on extremely rough country.

The township corners and property lines are identified on the prints in the field and these corners are worked into their true position by cutting in the corners with radial control. In some areas where the section lines cannot be distinguished, as in a heavily wooded country, lime circles 50' in diameter and 6' wide are constructed around the township corners before the area is flown. These lime circles are worked into the radial control net giving us the location of the township corners. With their aid and the information from the old General Land Office plats the section line grid is worked up. These lines are traced on the back of the map so that if any discrepancies are found they can be corrected without damaging the topography.

## Controlled Mosaics

After the planometric map is completed a photographic reduction is made to the scale of 1:20,000. This print is to serve as the control for our mosaic. Each picture is ratioed or transformed by tilting in a transforming camera so that the images on the picture coincide with the images on the map. These small portions of pictures are fitted over the data on the planometric map, constructing the mosaic with as few distortions as possible.

Now we have an accurate picture record of the area before the Soil Conservation Service started erosion work on the project which, I believe, will be invaluable in future years.

# STANDARD METHODS OF MAKING REPRODUCTIONS FROM DRAWINGS AND TRACINGS

by

W. F. Beamon
Chief Draftsman, S. C. S.

After drawings or tracings have been made, the next important thing is to make reproductions from them. There are a great number of different methods of reproduction on the market today so it is necessary to take in consideration the use, time element, number of copies necessary and the cost in determining the correct reproduction for each individual job. Therefore it is my intention to give a general outline, from the layman's standpoint, of the standard reproduction methods in use today.

## BLUEPRINTS

The blueprint is the most used of these reproduction methods, when the drawing is on tracing cloth, vellum or other transparent material. In making a blueprint a sensitized paper is used. The general commercial blueprint papers are prepared by being coated with a solution of potassium ferrocyanide and sulphide of iron. For general uses it is cheaper to buy a commercial paper rather than attempt to prepare it for individual jobs. Where it is necessary, however, to make blueprints on heavy paper, cardboard, or other special surfaces it is best to prepare the surface for each individual job as follows:

Solution "A"

Green citrate of iron.....1 oz.
Water.....4 oz.

Solution "B"

Red prussiate of potassium.....1 oz.
Water.....7 oz.

These solutions are mixed and kept separate until ready for use. Then Solution "A" and "B" are mixed in equal parts and applied evenly to the surface of the paper with either brush or cotton. The paper is then hung up to dry before using.

We are now ready for making the finished blueprint which is made by exposing the coated surface to an Arc light or sunlight, the light being projected through the vellum or other transparent material on which the drawing has been made. When exposed to light the cyanide coating is burned into all surfaces of the paper except those sections which are protected by the lines on the drawing. The paper is then washed in water and those sections that were protected from the action of the light are washed off leaving white lines in the places where black lines appeared on the original tracing. To intensify the blue background and prevent fading, it is best to now coat or wash the prints with a solution of potassium bichromate or peroxide of hydrogen for a few seconds and then rinse in clear water before drying.

The advantages of blueprints are, that they can be made most any place that sunlight is available and with the construction of very little equipment, a sun-frame for printing and the chemical solutions being all that are needed. The disadvantages of blueprints are the shrinkage due to the washing process and the fact that it is hard to make a reproduction from blueprints. There are now machines on the market which make blueprints, complete and dry them in one continuous process, but the cost of these machines makes them prohibitive except for use in quantity production. There is also available a sensitized cloth on which blueprints can be made. Blueprints can be made from practically any transparent paper or cloth, but where the paper is heavy or opaque, it is best, before exposing, to treat this paper with a transparentizing solution of which there are several commercial brands on the market today. A good home-made solution is a mixture of paraffin and carbon tetrachloride, also a suitable solution can be made by mixing pyroxylin and diacetose or acetone. This solution will also water-proof paper. Where the above are not available a solution can be made of two or three parts gasoline to one part white mineral oil, after paper has been coated with these solutions it should be dried before exposing to the blueprint. Where white mineral oil is not available, castor oil may be substituted, but is not as desirable as it leaves a greasy surface.

## VAN DYKE NEGATIVES

The Van Dyke is a paper negative with transparent white lines and a dark brown background which is opaque. To make this negative, the manner of exposing the tracing is the same as stated for blueprints, but the paper used is very thin and the sensitized coating is a solution of silver nitrate. After the paper has been exposed to light, it is washed in water, then submerged for a few seconds in a fixing bath of sodium hyposulphide, then rinsed in water. Before the Van Dyke negative is used, it is best to treat this with one of the transparentizing solutions so that prints made from this negative will have clearer lines and whiter background.

## BLUE LINE PRINTS

After the Van Dyke negative has been made this can be used in place of the tracing and when exposed to blueprint paper in the same process as for making blueprints the finished product will be a blue line print, which is, the reverse of a blueprint, or blue lines on a white background. The advantages of blue line prints are, that they can be used for making notations and pen and ink studies on the white background, also, by using the Van Dyke negative for exposures, the original tracing is preserved.

## BROWN LINE PRINTS

Brown line prints are made in the same manner as blue line prints except the paper used is coated with a silver nitrate solution and the same fixing bath is used as in making Van Dyke negatives , except that sulphuric acid is added drop by drop to the hypo solution until it has a milky appearance. This gives the prints a whiter background. Brown line prints have the same advantage as blue line

prints and for photographic purposes are much superior as blue lines will not photograph. Their only disadvantage is that the cost is higher than for blue line prints.

## DIRECT PROCESSES

There has always been a demand for a direct process of printing that would answer the purpose of a blueprint. There are now on the market commercial processes by which direct red line, black line, brown line, and blue line prints can be made.

## OZALID PRINTS

The Ozalid print which consists of red lines on a white background is made by using a paper which has been chemically treated by a secret process. It is exposed to light the same as for making blueprints, but after being exposed the paper is placed in some type of closed container, and subjected to ammonia fumes, which develops the lines. The advantages of Ozalid prints are that, as they do not require washing, there is practically no shrinkage or stretch, and that they can be made very quickly. The disadvantages are that the chemicals used make the paper very brittle and it usually has a yellow cast. Also the tracing must be new and in good condition or the fine lines and lettering will be fuzzy and faded in the final reproduction.

## DIRECT BLACK LINE, BROWN LINE AND BLUE LINE PRINTS

Black line, brown line and blue line prints are made from papers that have been chemically treated by secret processes. They are exposed in the same manner as for making blueprints. The development, however, is different as the lines are produced by coating the paper after exposure with a chemical developing solution, each paper requiring a different solution which is a secret formula of the paper manufacturers. This process is very suitable for use in field offices, as it is only necessary to sponge the developing solution lightly on the face of the paper after it has been exposed. This eliminates the need for trays and fixing baths. The advantages of these prints are that they are simple to make and not being washed there is very little shrink or stretch. The disadvantages are that, being chemically treated, they will not stand much hard usage and, as they crack and split when rolled very much, they should always be filed flat. Some manufacturers are now putting out developing machines which apply a very light film of developer to the surface of these papers quickly and in a more uniform manner than by hand.

## REPRODUCTIONS ON TRACING CLOTH

The first process used for reproducing an image on tracing cloth without actually tracing same, is sometimes called the jelly process, but it is also known by a great many trade names. To make this reproduction, a blueprint if made from the original tracing, without being washed or developed, is laid on a prepared jelly which has been allowed to harden. The image which would have been washed off, if the print had been developed,

transfers to the surface of this hardened jelly. The room in which the work is done must be kept between 50° and 70° Fahrenheit. The slab of jelly is now inked with a greasy ink, the ink only adhering to the image that was transferred from the blueprint. The tracing cloth or paper is then laid on the inked slab and rolled uniformly with a roller and when removed it will be found that the ink has transferred itself from the jelly slab to the tracing cloth, paper or other material used. The advantages of this process are that it is economical and fairly quick; also colored inks may be used and several different colors transferred to one tracing. The disadvantages are, that the ink will sometimes chip off the tracing if the ink is too dry, and if it is not dry enough it will smudge and smear. The newest process of reproducing on tracing cloth is to make a Van Dyke or photographic negative from the original tracing and to print these photographically on a waterproof tracing cloth which has been coated with a photographic emulsion. The advantages of this method are that the cloth itself is waterproof. The image, not being inked, there is nothing to chip or smudge and that the finest detail can be reproduced. This cloth will stand a great deal of erasing, and correcting and rough handling; also the shrink and stretch is much less than non-waterproof cloth. The disadvantages are that this method is fairly expensive and the lines cannot be reproduced in colors.

## PHOTOSTATS

Where the drawing or image is on heavy paper or other material which cannot be reproduced by the processes mentioned or where it is necessary to enlarge or reduce from the original, it becomes necessary to resort to a photographic process. The best known and most economical is the photostat. Photostats are made by photographing any flat surface onto a sensitized paper through a prism, which is placed either in front or in back of the lens. The exposed paper is developed in a chemical solution, then fixed in a fixation bath and washed, similar to developing a photograph. This gives white lines on a brown background and is generally known as a photostat negative. Where positive copies are required this negative is then rephotographed following the same process and the result is a dark brown line on a white background. Where necessary to make a reproduction which is too large for a standard photostat machine, which is 18 x 24 inches, it is necessary to either reproduce in sections and paste together or resort to the photoprint process. The advantages of photostats are that they can be made very quickly and economically. The disadvantages are that, due to the curvature of the lens and the sensitized paper being suspended between rollers and not on a flat surface, there is nearly always distortion in the finished product.

## PHOTOPRINTS

An improvement on photostats is the product called photoprints now produced in the larger cities. In this process the image is reflected through a camera onto a negative paper which is held flat, either by vacuum or a sheet of glass in front of the paper. After the image has been reflected onto the negative paper it is developed in the same manner as a photograph. These prints can be made in any size up to 40 x 60 inches

and reproductions can be made from blueprints, blue line prints or most any other flat image. The advantages of these prints are the range of sizes. The improved contrast due to the use of arc lights, and as the best type of lenses are used in this work, a better reproduction from the original is secured. The disadvantages are the slight shrinkage due to the developing and washing process and the work has to be sent to a large city where equipment is available for doing this work.

## PHOTOLITHOGRAPHY

Nearly all lithography is now done by what is known as the photo-offset method. This method has been developed from experience gained during the past twenty years but is not as well known as it should be. The following steps are taken in producing photo-offset reproductions. The first operation in photolithography is making a negative from the subject. This negative is of such a nature that it can be cut and refined. After the negative is completed, opaqued, and cut, it is placed in a vacuum printing frame, film side down, on a bichromatic plate. This plate has been flowed with a solution of albumen and bichromate, whirled, and dried by heat. This work is done in a dark room as the solution on the plate is sensitive to light. The negative is placed against this plate in a vacuum frame and exposed to strong arc lights which photograph the image on the albumen plate. After exposure, the entire plate is covered with a developing ink, then placed in a tank of running water, which develops the image, leaving on the plate only the part exposed from the negative to the plate. From this step the lithographic transferer completes the process, and rolls up the plate with an ink roller, while it is still in a dampened condition. The plate is now covered with a rosin which only adheres to and protects the undeveloped areas while the plate is being etched with an acid containing gum arabic. This etch is virtually a chemical fire carbonizing the ink on the plate to form the image, and desensitizing the bare plate. The plate is then covered with gum solution, washed out with turpentine and covered with a thin coat of asphaltum solution. The plate is now ready to be put in a lithographic offset press, to run the finished prints on paper.

In making the finished copies in this offset press, a cylinder holding the plate revolves and receives continuously, at different points of the work, water and ink. The carbonized ink areas retain the ink which is supplied by sets of rollers while the other areas are covered by a hydroscopic film of water which repels the ink, this water being supplied by another set of rollers. This ink is printed or transferred to another cylinder holding a special rubber blanket. As the cylinder holding the rubber blanket revolves the greasy ink image is offset on the paper. For color reproductions it is necessary to make a separate plate and printing for each color combination. It is necessary, of course, to allow each printing to dry before the next printing is superimposed upon it. The above is a brief sketch of photo-offset lithography. To secure a high type of work a very fine press must be used which can be adjusted to a perfect register. The great advantage of photo-offset lithography is that any drawing or print may be reproduced in quantity, at small cost and on any kind of paper.

## ROTAPRINTS

Many small presses known by various trade names are now being manufactured in an endeavor to build a small offset press to compete with the true photo-offset press. The products of these are usually called rotaprint. These presses have power rollers to distribute the ink which require less adjustments and are spaced to require less skilled men to operate them than regular presses. Experience has shown that these presses will produce better work than the mimeograph or multigraph, and are used a great deal for reproducing small black and white maps in large quantities. The process for making the plates is the same used in making lithograph plates, but the presses for this work are not to be compared in any way with the regular photo-offset press. As long as their operations are confined to black ink and straight line work very passable results are produced. These presses are not very well adapted for a close register, color work, or very fine line work such as would be necessary for maps reduced down in size. Atmosphere, moisture of paper, distribution of the ink, and lack of adjustments are the elements which prevent these smaller machines from producing the highest quality of map work. They are comparable to photostat, being a cheap method of getting fair grade reproductions.

Based on standard prices in Washington, D. C., the following is the number of copies one foot square, that can be reproduced for $3.00 by the various methods which have been outlined.

| Name of Reproduction | Cost per Sq. Ft. | No. of Copies 1 Ft. Sq. that $3.00 will buy | Remarks |
|---|---|---|---|
| Blue Prints | 4¢ | 75 | |
| Blue Line Prints | 4¢ | 75 | Negative extra |
| Van Dyke Negative | 10¢ | 30 | |
| Brown Line from Van Dyke | 10¢ | 30 | |
| All Direct Process Prints | 5¢ | 60 | |
| Photostat | 30¢ | 10 | |
| Photoprint | 30¢ | 10 | |
| Litho-prints | | 280 | $2.50 - 1st 100, .35 - Each add. 100 |
| Rotaprints | | 400 | |
| Cloth Reproduction by Jelly process | 30¢ | 10 | |
| Cloth Reproduction by Photo process | 60¢ | 5 | |

# DIAGRAMS FOR USE IN HYDRAULIC DESIGN OF EROSION CONTROL STRUCTURES

by

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The attached diagrams and tables are to appear in a forthcoming handbook for the field engineers of the Soil Conservation Service. They are distributed prior to publication in order that they may be available for field use at the earliest possible moment.

A rather extended discussion of the hydraulic design of erosion control structures will be included in the handbook above mentioned. As a present help in the use of the diagrams the following brief descriptions are appended:

Figures 1, 2, 3, 4.

These diagrams are for use in the design of small open channels of trapezoidal cross-section. They are based upon the Manning formula:

$$Q = \frac{1.486}{n} AR^{2/3} S_b^{1/2}$$

Each figure is for a section of given side slope, thus:

| Figure | Side Slope or Batter |
|---|---|
| 1 | Vertical sides |
| 2 | 1 to 1 |
| 3 | 1.5 to 1 |
| 4 | 2 to 1 |

The notation employed is:

$Q$ = rate of flow in cubic feet per second (CFS)
$D$ = depth of water above bed in feet
$b$ = width of bed in feet
$A$ = area of cross-section of water in square feet.
$R$ = hydraulic radius or A divided by "wetted perimeter":feet
$S_b$ = slope of channel bed
$n$ = value of "roughness coefficient" in Manning formula (see Table II)

To use any diagram proceed as follows:

1. Having given $Q$, $S_b$ and $n$, compute the quantity $\frac{nQ}{1,486\sqrt{S_b}}$

2. If a channel with a particular bed width - depth ratio is desired, find the intersections of a vertical line through the chosen $b/D$ with a horizontal line through the computed value of

FIGURE 1

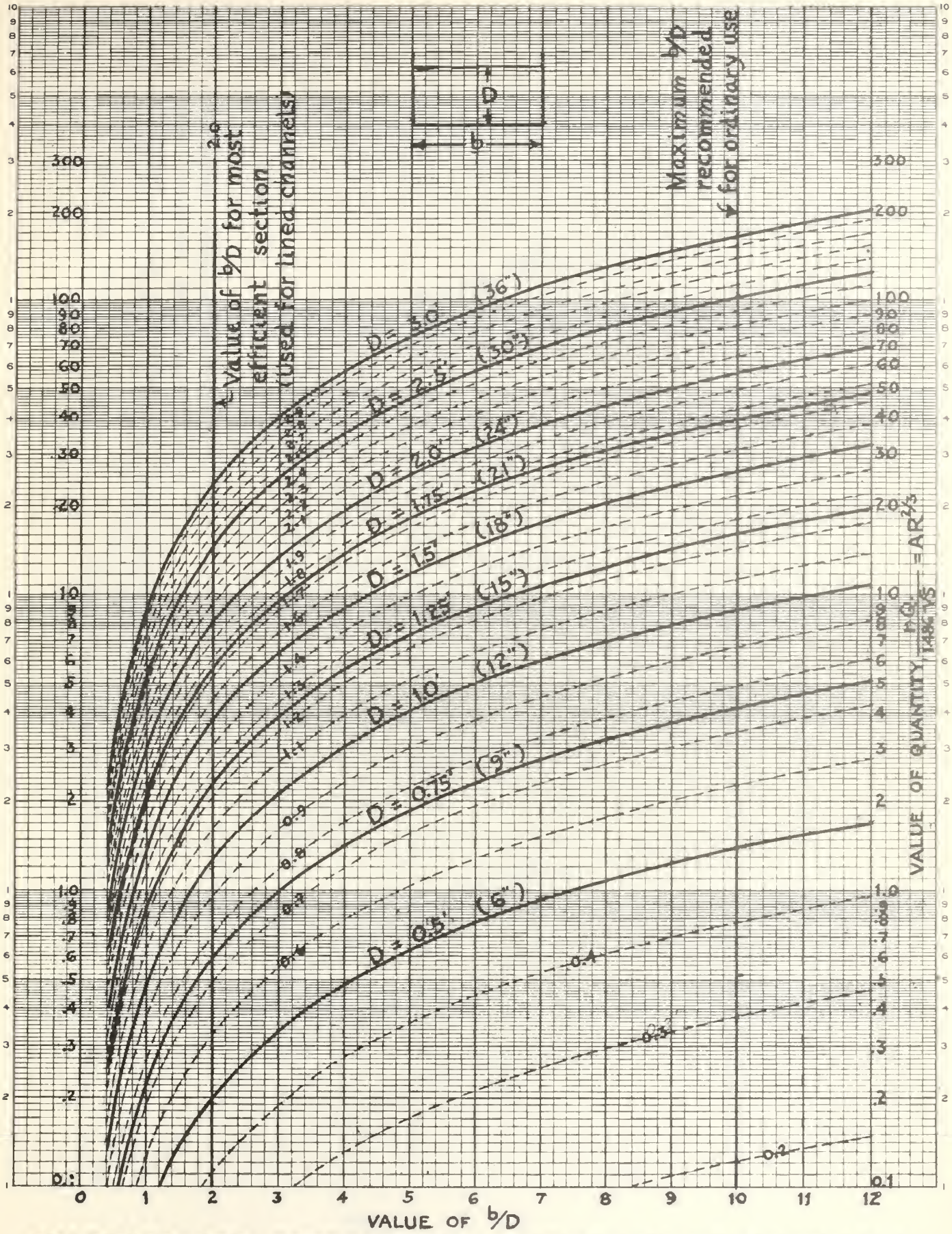



DIAGRAM FOR DETERMINING DIMENSIONS OF CHANNELS HAVING VERTICAL SIDES

FIGURE 2

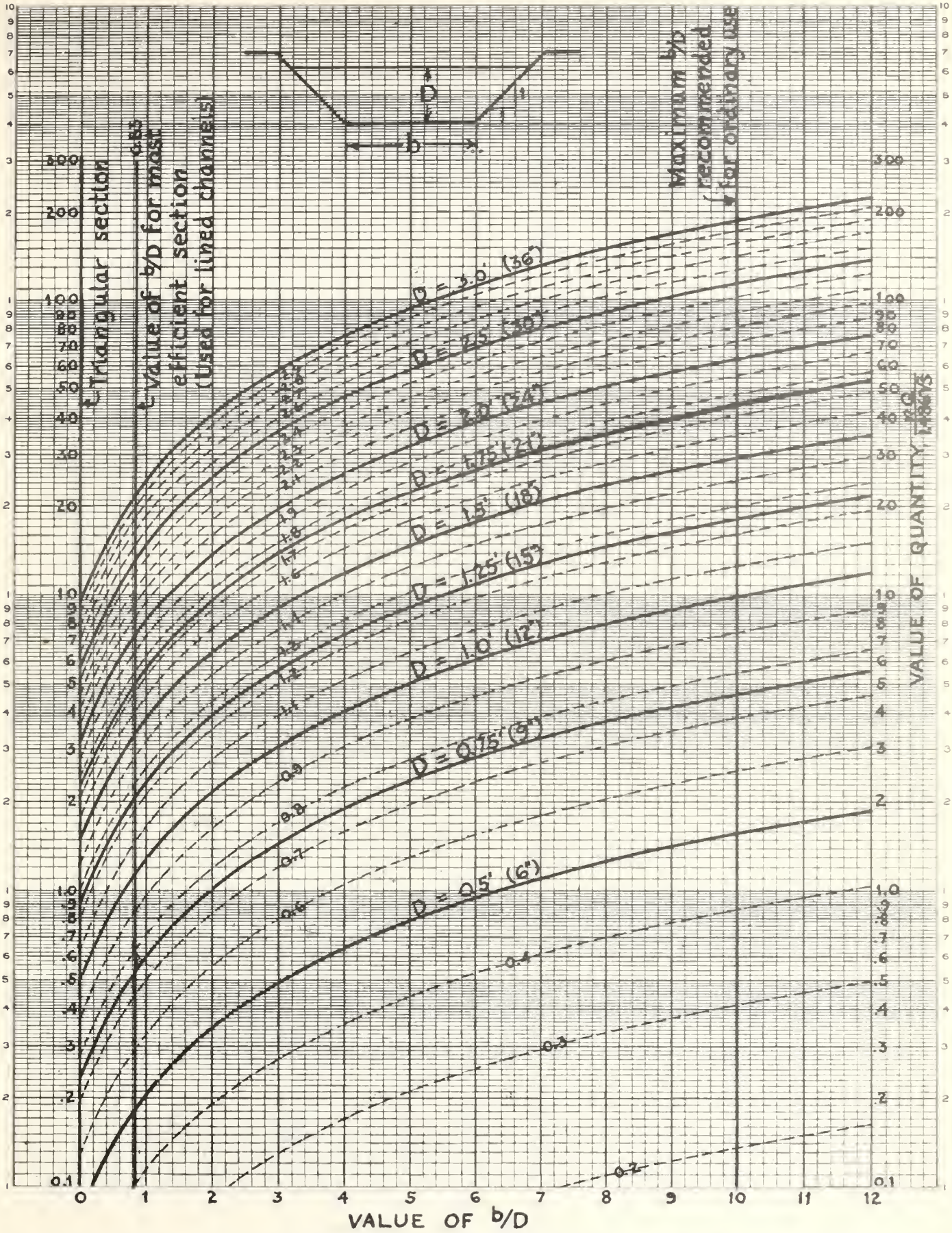



DIAGRAM FOR DETERMINING DIMENSIONS OF CHANNELS HAVING SIDE SLOPES OF 1 HOR. TO 1 VERT.

FIGURE 3

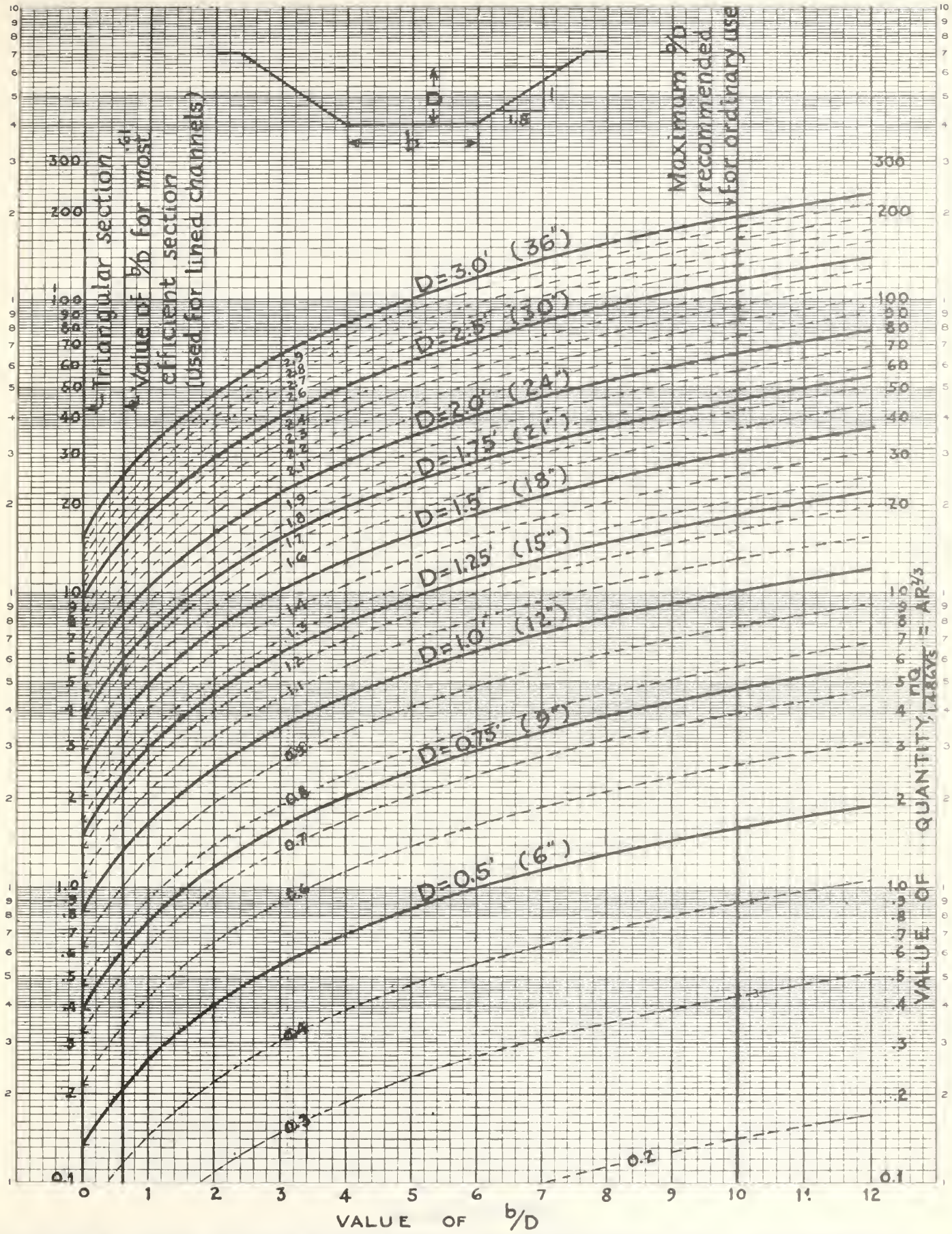



DIAGRAM FOR DETERMINING DIMENSIONS OF CHANNELS HAVING SIDE SLOPES OF 1.5 HOR. TO 1 VERT.

FIGURE 4

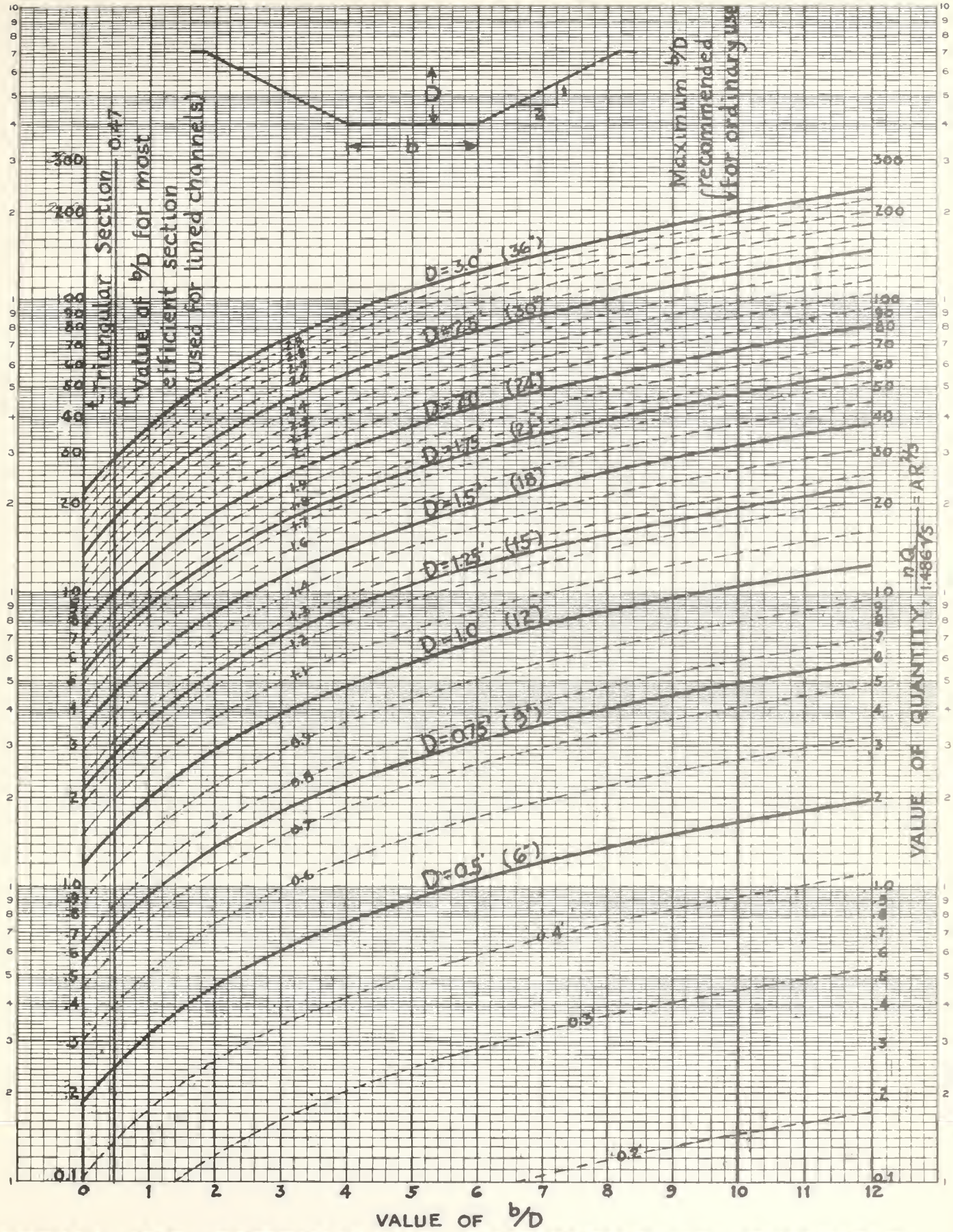



DIAGRAM FOR DETERMINING DIMENSIONS OF CHANNELS HAVING SIDE SLOPES OF 2 HOR. TO 1 VERT.

Fig. 2-A

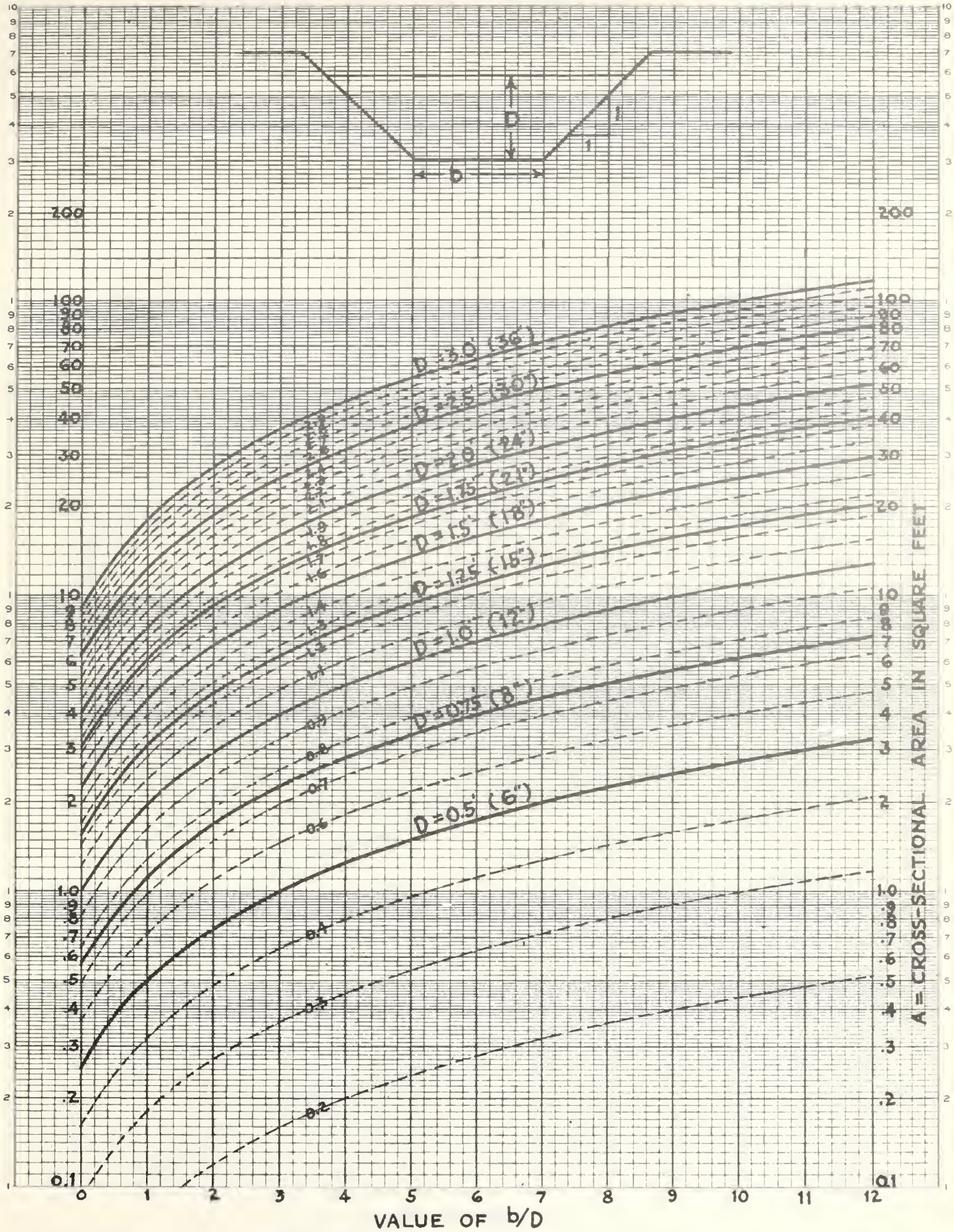



DIAGRAM FOR DETERMINING AREAS OF CHANNELS HAVING SIDE SLOPES OF 1 HOR. TO 1 VERT.

Fig. 3-A

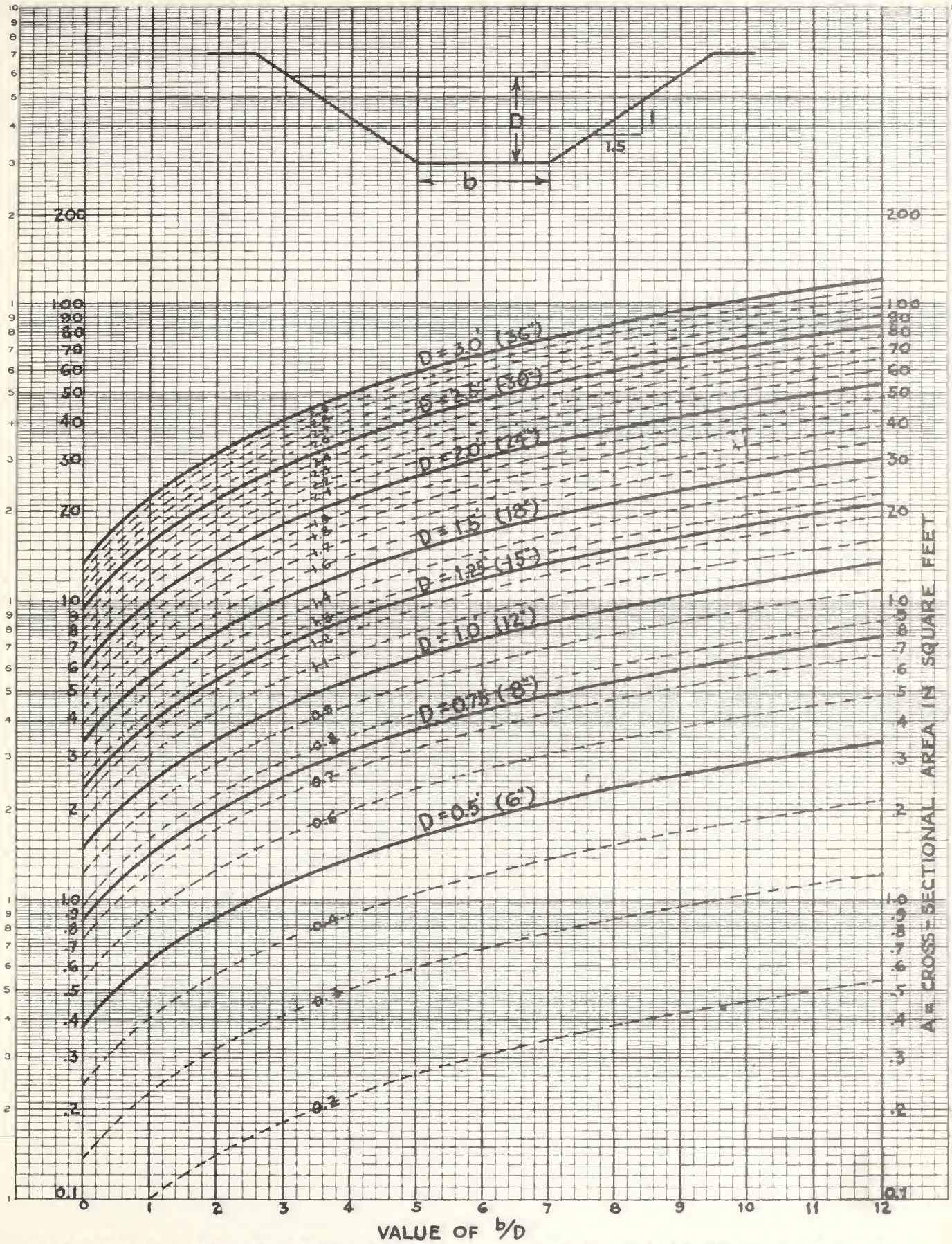



DIAGRAM FOR DETERMINING AREAS OF CHANNELS HAVING SIDE SLOPES OF 1½ HOR. TO 1 VERT.

Fig. 4-A

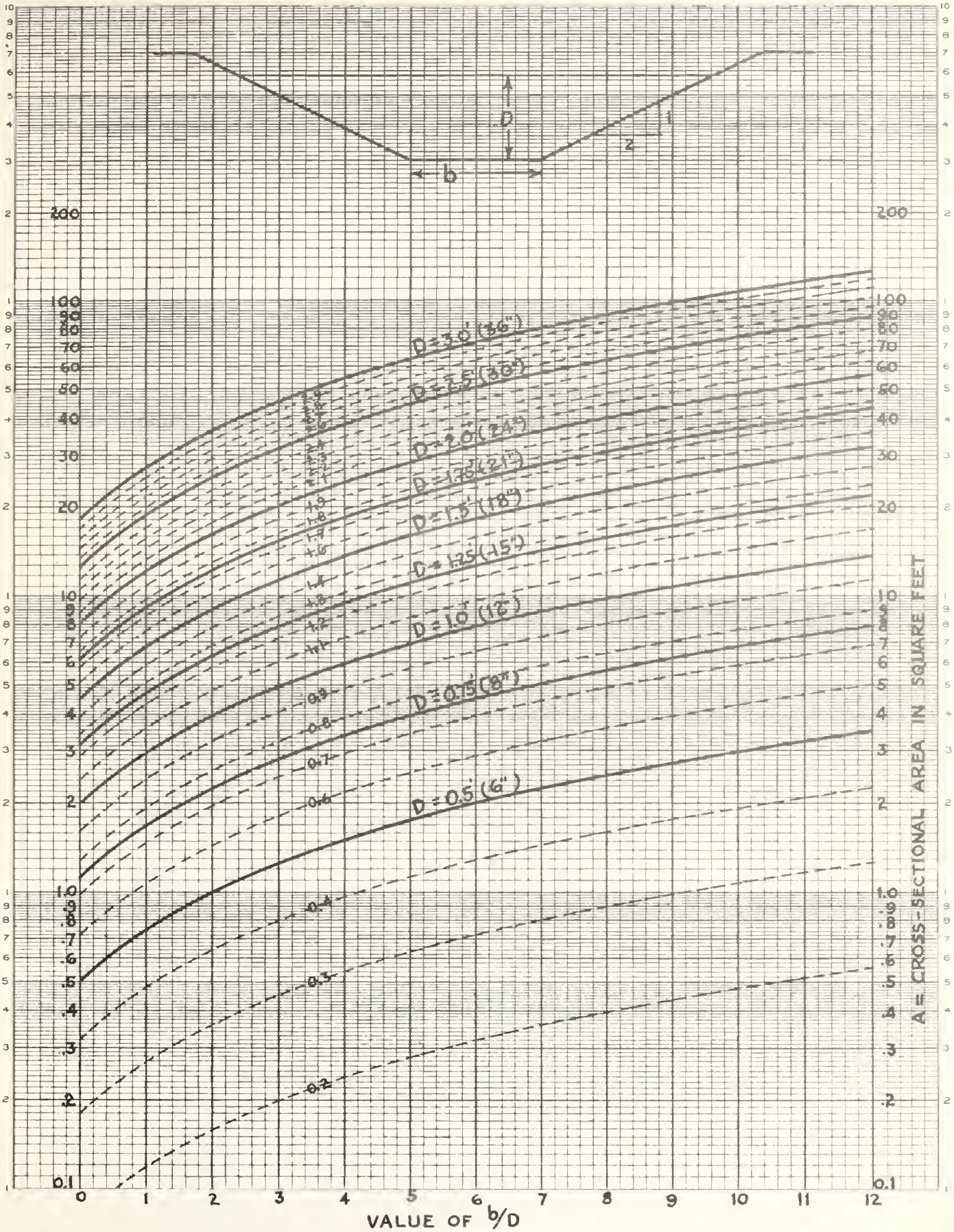
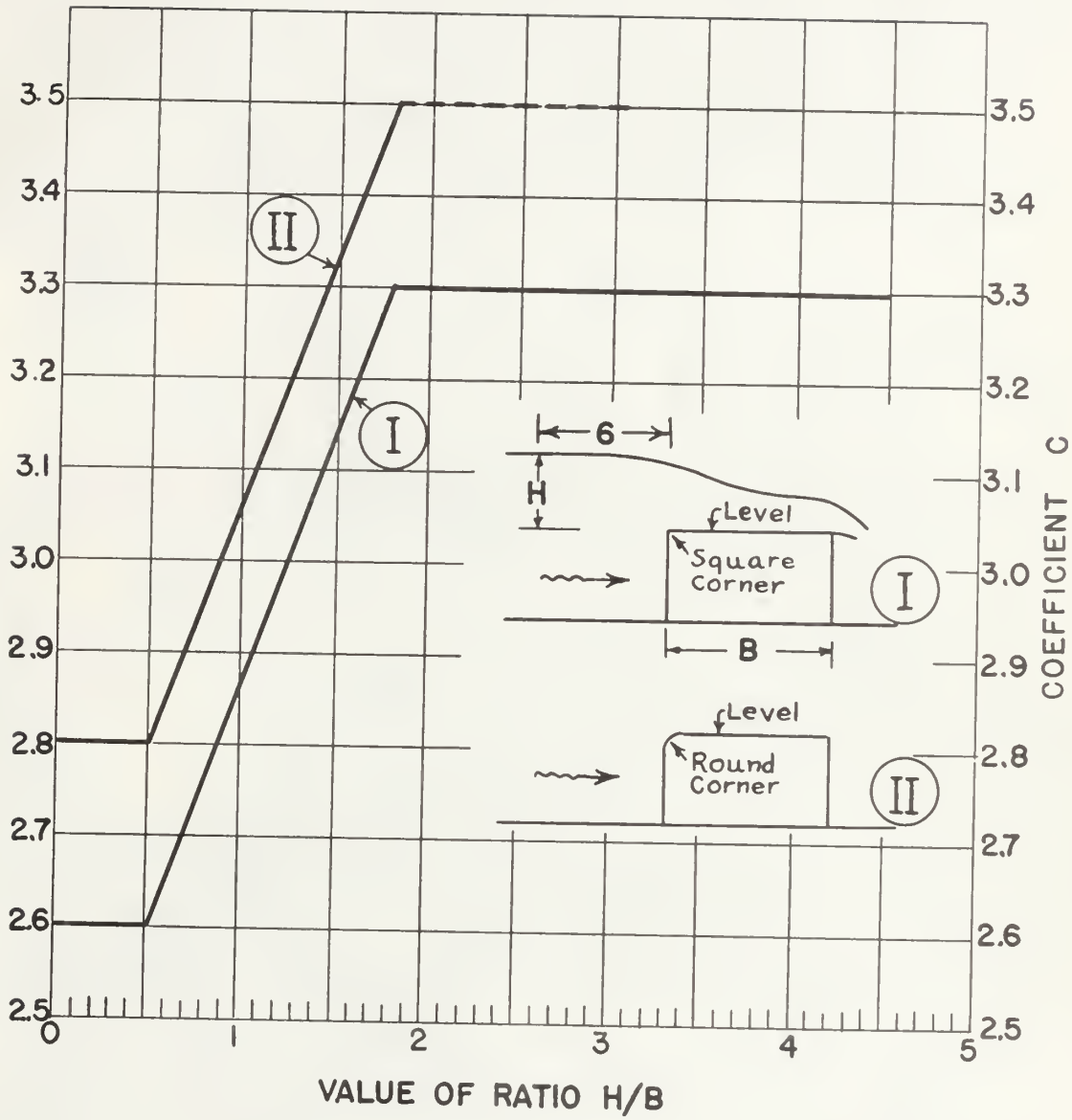



DIAGRAM FOR DETERMINING AREAS OF CHANNELS HAVING SIDE SLOPES OF 2 HOR. TO 1 VERT.




COEFFICIENTS FOR BROAD CRESTED WEIRS
HAVING LEVEL CRESTS

$\frac{n\,Q}{1.486\sqrt{S_b}}$. The number on the curve lying nearest this intersection indicates the approximate depth at which the water will flow in a channel of the required proportions. If desired, interpolation between the curves may be used to establish the depth more closely.

3. If a channel of given depth is desired, find the intersection of the curve marked with this depth and a horizontal line through the value of $\frac{n\,Q}{1.486\sqrt{S_b}}$. The value of b/D vertically below the intersection gives the relative proportions of the channel.

Example: Side slope 1.5 to 1
$Q = 10$ CFS, $S_b = .01$, $n = .04$
$\frac{nQ}{1.486\sqrt{S_b}} = 2.69$

| b/D (Assumed) | D | b | |
|---|---|---|---|
| 0 | 1.53 | 0 | (Triangular section)* |
| .61 | 1.30 | .79 | (Most efficient sec.)* |
| 5 | 0.78 | 3.9 | |
| 10 | 0.60 | 6.0 | (Widest section) |

Anyone of the channels described above will carry 10 CFS. The final choice of dimensions would be based upon attendant circumstances.

To sumplify the computations required in the application of the diagrams, Table III, giving values of the quantity $1.486\sqrt{S_b}$, is appended.

It is recommended that channels designed for flood flows be proportioned so that b/D does not exceed 10.

Figures 2-A, 3-A, 4-A

From these diagrams may be obtained the cross-sectional areas of the channels designed by use of Figures 2, 3 and 4.

It is necessary to have these areas to compute the velocity, V, that will exist in the designed channel. V is easily computed from

$$V = Q/A$$

Each area diagram immediately follows the design diagram for the same side slopes. An area diagram for rectangular channels is omitted since the area is simply computed from $A = bD$.

Figure 7

This diagram provides approximate values of the weir coefficient, C, for rectangular weirs having broad, level crests. The standard formula used to calculate the discharge of such weirs is

$$Q = CLH^{3/2}$$

in which

* These sections to be used only where channel is lined.

H = head on crest of weir, in feet, measured about 6 feet upstream
L = length of crest of weir in feet
B = breadth of crest of weir in feet

The diagram should be used only for heads greater than 0.5 foot.

If the desired H and B for use in design are known the ratio H/B is computed and the diagram entered to find C without further effort. If H is unknown it is necessary to employ a process of "cut and try". For a first trial a tentative ratio is estimated and C taken from the diagram. Using Figure 9, the value of H corresponding to the chosen C is found and the value of H/B recomputed. With this corrected ratio Figure 7 is again entered and C redetermined. After two or three trials H and C may be brought into sufficiently close agreement.

Figure 8:

The values of C given by this diagram are to be used only for rectangular notches on the crests of vertical falls. The values of C given by the diagram are conservative, that is, slightly smaller than those that would probably be found by experiment. They apply only for values of H greater than 0.5 foot.

The manner of using this diagram is rather obvious. In design it is often necessary to proceed by "cut and try" in a manner somewhat similar to that described in discussing Figure 7.

Figure 9:

Diagrams of this nature are called alignment charts or nomographs. They are used as follows:

Having given two of the variables; they are located on their respective axes and a straight edge passed through them; the value, of the unknown variable is read at the intersection of the straight edge with the third axis.

Figure 9 is used for the solution of the equation

$$Q_1 = CH^{3/2}$$

where $Q_1$ represents the discharge of a rectangular weir per foot of weir crest. To use the diagram divide Q by L to find $Q_1$, decide upon the proper value of C and determine H from the chart. To determine L it is best to proceed by trial, assuming several values of L and finding the values of H corresponding to each. The desired combination of H and L may be found by interpolating between these trial values. It should be remembered that

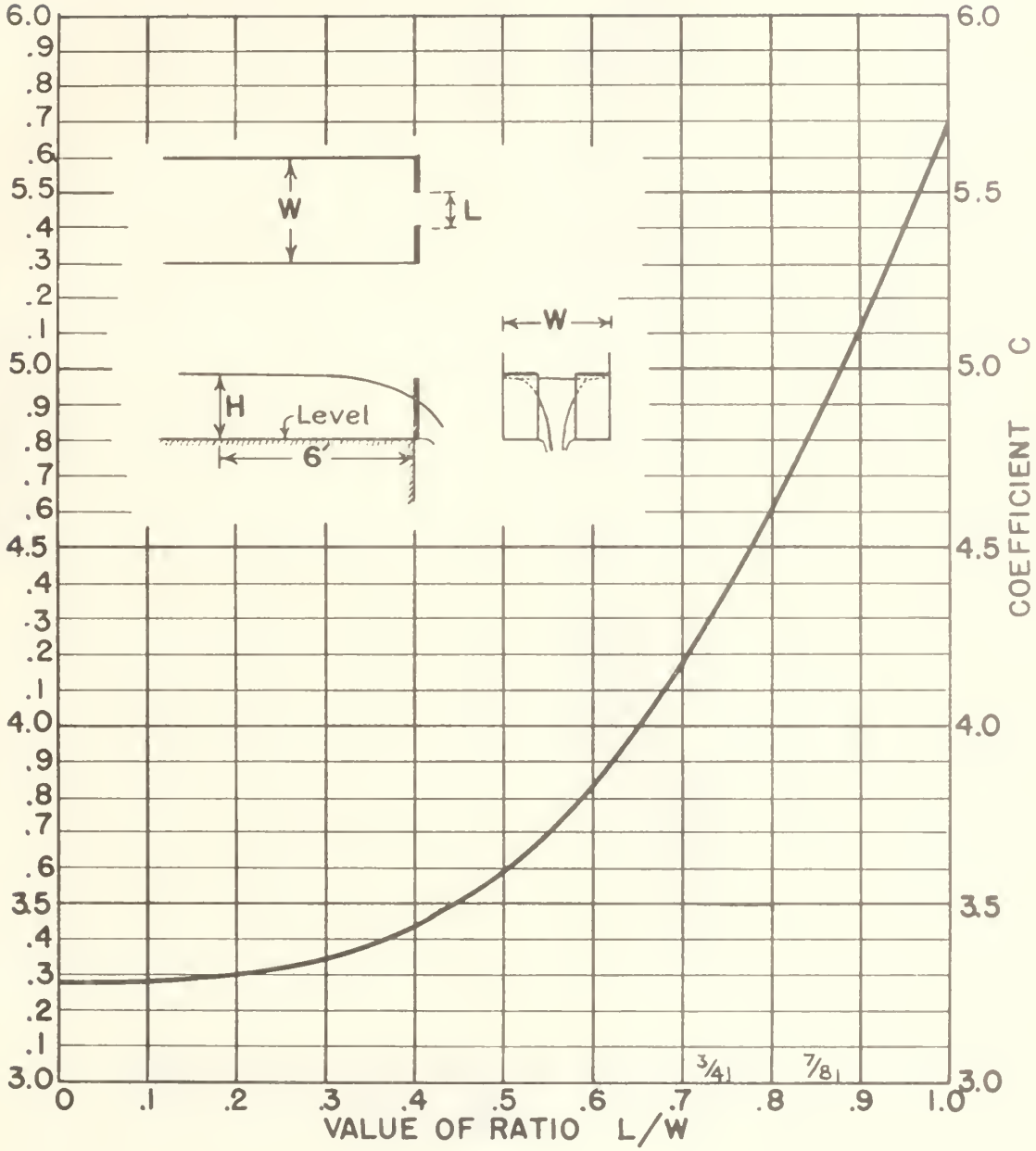
$$L = Q/Q_1$$

Figure 10:

This is an alignment chart for the solution of the equation

$$Q = 3.33\ LH^{3/2}$$

Fig 8




COEFFICIENTS FOR RECTANGULAR NOTCHES
ON THE CREST OF A VERTICAL FALL

Fig. 9

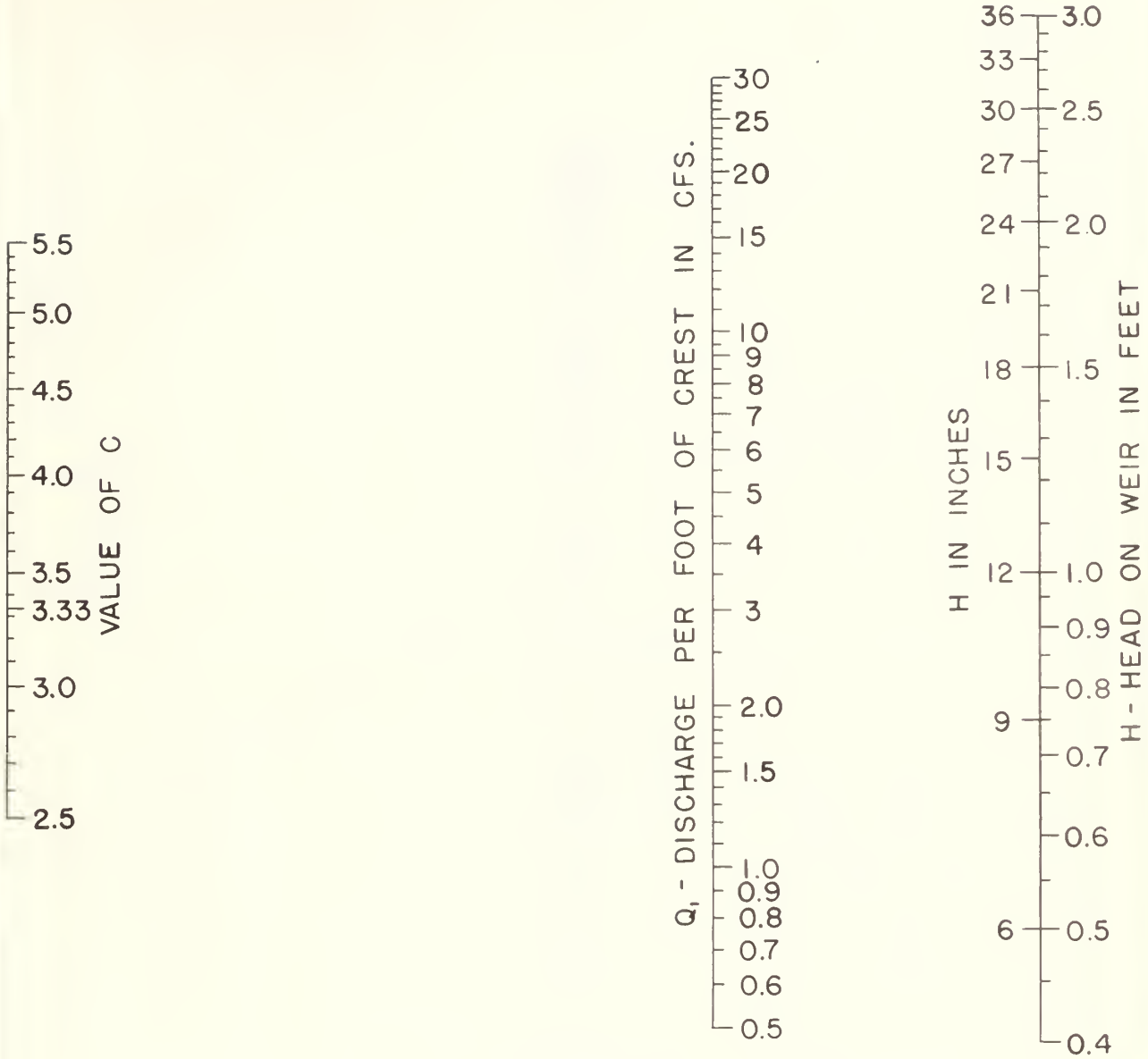
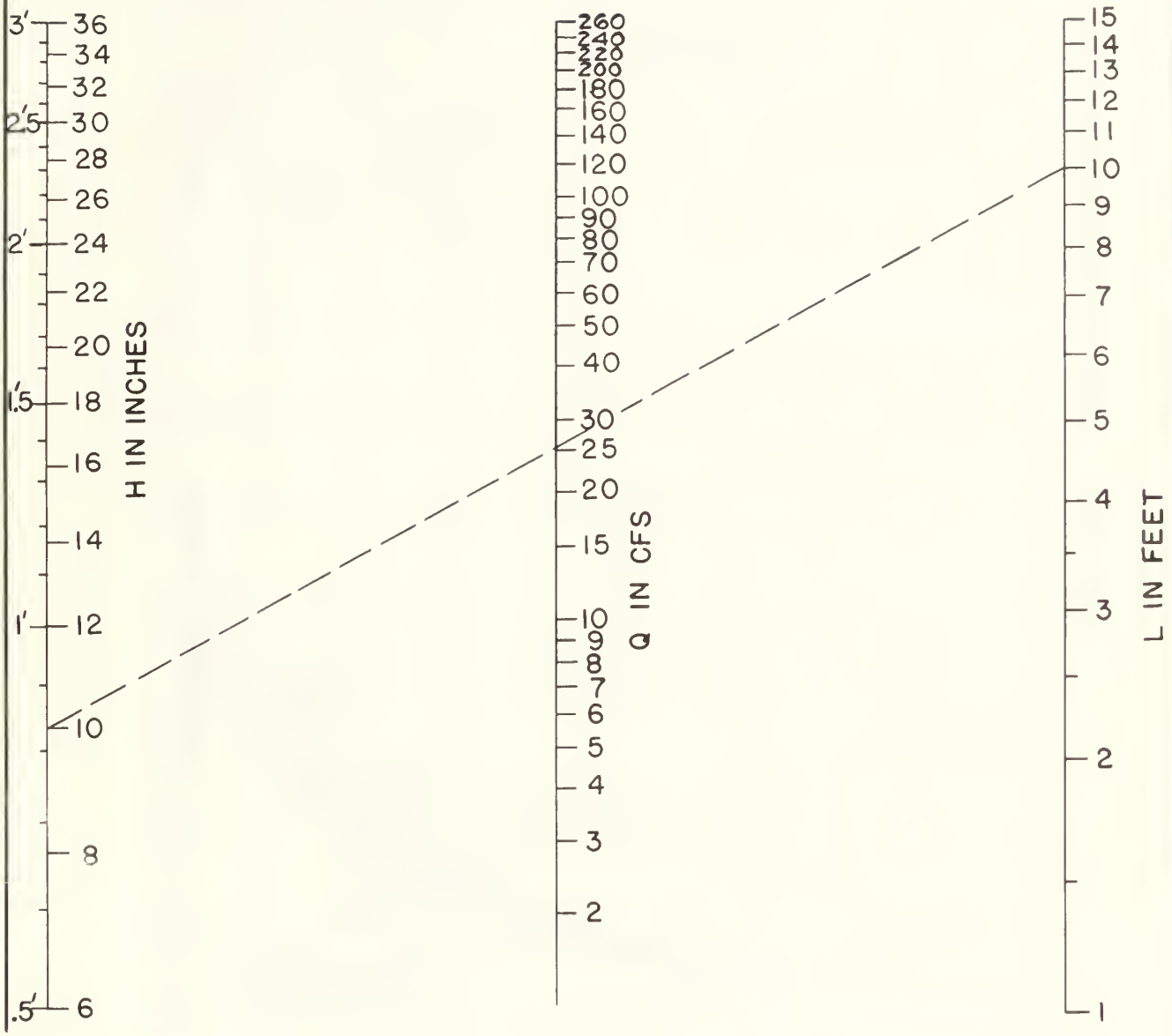



CHART FOR SOLUTION OF EQUATION

$Q_1 = CH^{3/2}$

Fig. 10

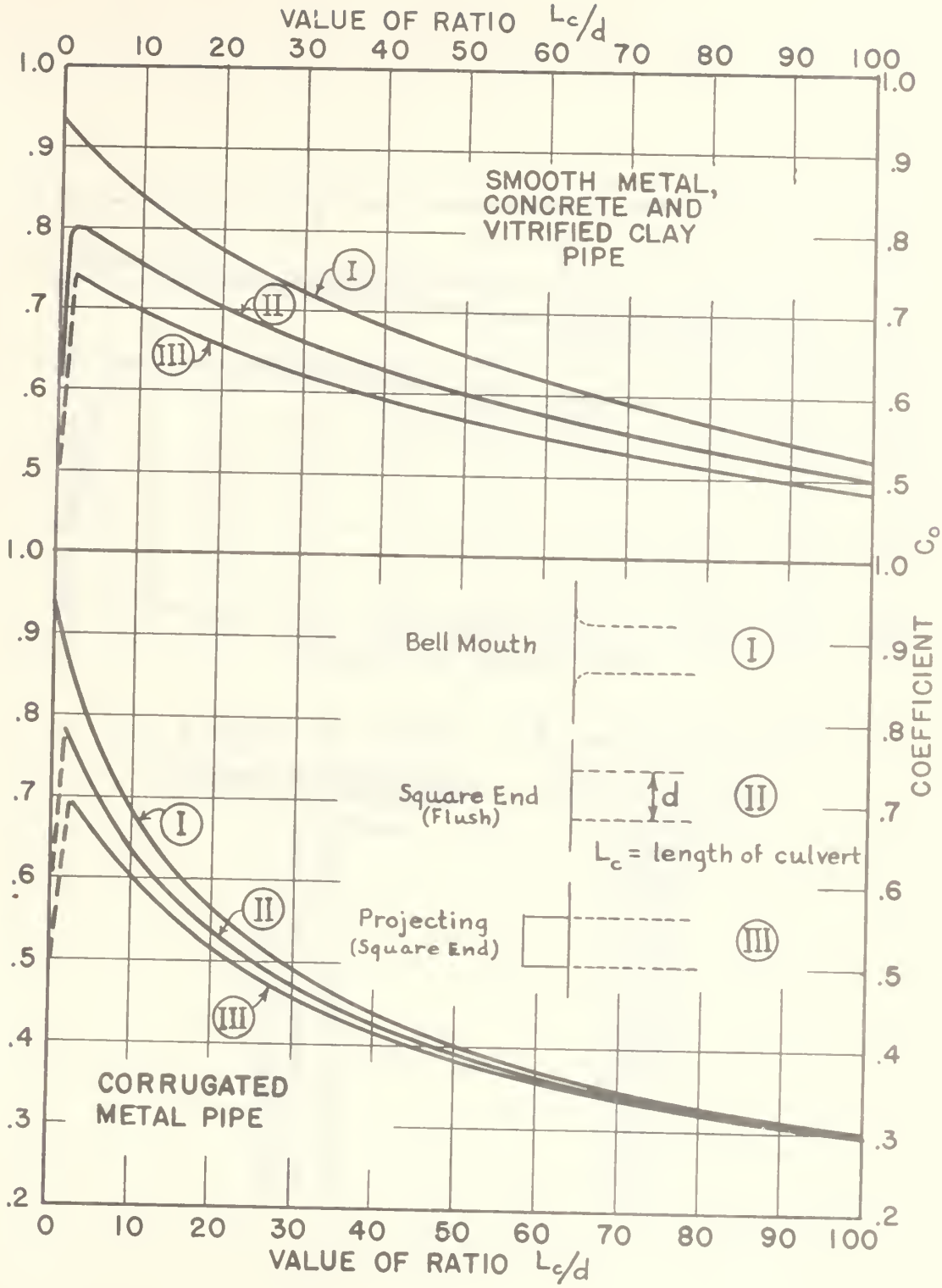



$Q = 3.33\ LH^{3/2}$

Q = CFS

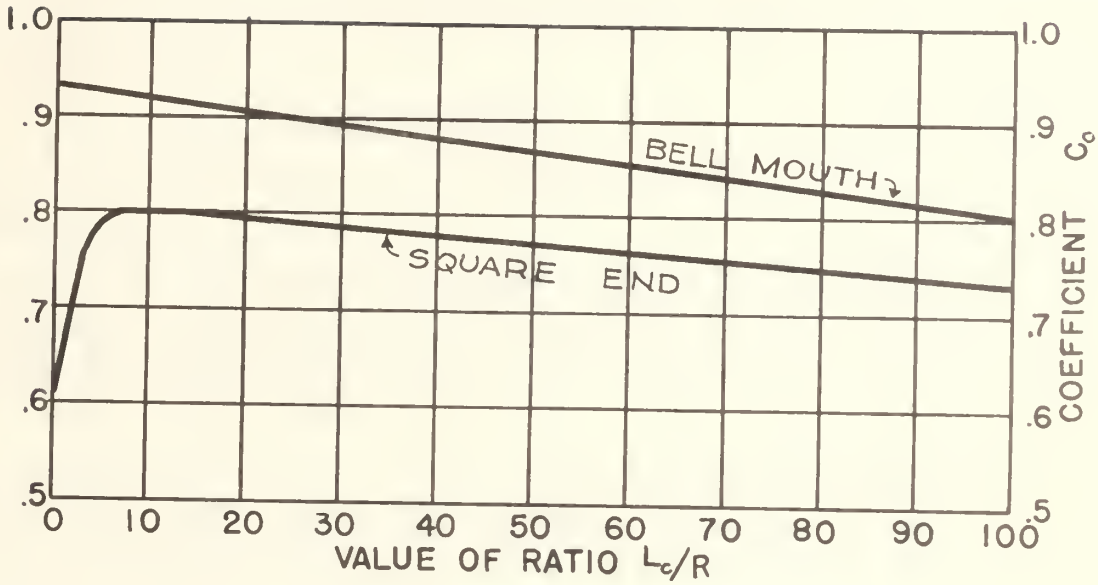
L = FT.

H = FT.




COEFFICIENTS FOR

# PIPE CULVERTS




$L_c$ = Length of culvert  R = Hydraulic radius

| CULVERT DIMENSIONS | VALUE OF R |
|---|---|
| 1 X 1 Feet | .250 Feet |
| 1 X 2 | .333 |
| 1 X 3 | .375 |
| 2 X 2 | .500 |
| 2 X 3 | .600 |
| 2 X 4 | .667 |
| 3 X 3 | .750 |
| 3 X 4 | .857 |
| 3 X 5 | .938 |
| 4 X 4 | 1.00 |
| 4 X 5 | 1.11 |
| 5 X 5 | 1.25 |
| 5 X 6 | 1.36 |
| 6 X 6 | 1.50 |

COEFFICIENTS FOR

# CONCRETE BOX CULVERTS

When the weir coefficient C is in the neighborhood of 3.33 this diagram may be used to find L or H directly, and without recourse to Figure 9. The chart is also useful in preliminary design and in finding tentative values of H and L with which to enter Figure 9.

Figures 15 and 16:

On these diagrams are curves giving values of the culvert coefficient $C_o$ in the formula

$$Q = C_o A\sqrt{2gh}.$$

A sufficient number of curves are given to cover the types of culverts in ordinary use.

Values of $C_o$ taken from these diagrams should be used only for submerged culverts, that is, for culverts operating with both ends under water. The value of h to be used in this case is the difference in elevation of the water surfaces just above the entrance and just below the outlet of the culvert.

The diagrams are used in a fairly obvious manner. Having given the length of the culvert, $L_c$, assume tentative dimensions and compute $L_c/d$ or $L_c/R$. Enter the diagrams to find $C_o$ and compute Q. If the value of Q is not as desired it is only necessary to modify the trial dimensions and repeat the computation.

In Table VIII values of the quantity $\sqrt{2\ gh}$ are given to facilitate the computation of Q from the above formula.

## TABLE II

### COEFFICIENT n IN THE MANNING FORMULA

| Description of Channel Lining | Value of n |
|---|---|
| **LINED CHANNELS** | |
| Planed plank | .012 |
| Unplaned plank | .014 |
| Concrete | .015 |
| Good rubble masonry | .020 |
| Rough rubble masonry or dry rubble (rip-rap) | .025 |
| Rough rip-rap | .030 |
| **UNLINED CHANNELS IN EARTH** | |
| In excellent condition; no weeds or debris | .02 |
| Ordinary condition; low vegetation or gravel | .03 |
| Poor condition; weeds, tall grasses or rough bottom | .04 |
| Very poor condition; choked by weeds or willows | .05 |

TABLE III

| Slope $S$ | $\sqrt{S}$ | $1.486\sqrt{S}$ | Grade % |
|---|---|---|---|
| .0005 | .0224 | .0332 | .05 |
| .0010 | .0316 | .0470 | .10 |
| .0015 | .0387 | .0576 | .15 |
| .0020 | .0447 | .0664 | .20 |
| .0025 | .0500 | .0743 | .25 |
| .0030 | .0548 | .0814 | .30 |
| .0035 | .0592 | .0879 | .35 |
| .0040 | .0632 | .0940 | .40 |
| .0045 | .0671 | .0997 | .45 |
| .0050 | .0707 | .1051 | .50 |
| .0055 | .0742 | .1102 | .55 |
| .0060 | .0775 | .1151 | .60 |
| .0065 | .0806 | .1198 | .65 |
| .0070 | .0837 | .1243 | .70 |
| .0075 | .0866 | .1287 | .75 |
| .0080 | .0894 | .1329 | .80 |
| .0085 | .0922 | .1370 | .85 |
| .0090 | .0949 | .1410 | .90 |
| .0095 | .0975 | .1448 | .95 |
| .010 | .1000 | .1486 | 1.00 |
| .011 | .1049 | .1559 | 1.1 |
| .012 | .1095 | .1627 | 1.2 |
| .013 | .1140 | .1694 | 1.3 |
| .014 | .1183 | .1758 | 1.4 |
| .015 | .1225 | .1820 | 1.5 |
| .016 | .1265 | .1880 | 1.6 |
| .017 | .1304 | .1938 | 1.7 |
| .018 | .1342 | .1994 | 1.8 |
| .019 | .1378 | .2048 | 1.9 |
| .020 | .1414 | .2101 | 2.0 |
| .025 | .1581 | .2349 | 2.5 |
| .030 | .1732 | .2574 | 3.0 |
| .035 | .1871 | .2780 | 3.5 |
| .040 | .2000 | .2972 | 4.0 |
| .045 | .2121 | .3152 | 4.5 |
| .050 | .2236 | .3323 | 5.0 |
| .055 | .2345 | .3485 | 5.5 |
| .060 | .2449 | .3639 | 6.0 |
| .065 | .2550 | .3789 | 6.5 |
| .070 | .2646 | .3932 | 7.0 |
| .075 | .2739 | .4070 | 7.5 |
| .080 | .2828 | .4203 | 8.0 |
| .090 | .3000 | .4458 | 9.0 |
| .10 | .3162 | .4699 | 10 |
| .11 | .3317 | .4929 | 11 |
| .12 | .3464 | .5148 | 12 |
| .13 | .3606 | .5359 | 13 |
| .14 | .3742 | .5561 | 14 |
| .15 | .3873 | .5755 | 15 |
| .16 | .4000 | .5944 | 16 |
| .17 | .4123 | .6127 | 17 |
| .18 | .4243 | .6305 | 18 |
| .19 | .4359 | .6477 | 19 |
| .20 | .4472 | .6645 | 20 |

TABLE VIII

TABLE OF V - $\sqrt{2gh}$

| Value of h | .0 | .1 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 2.54 | 3.59 | 4.39 | 5.07 | 5.67 | 6.21 | 6.71 | 7.17 | 7.61 |
| 1 | 8.02 | 8.41 | 8.79 | 9.14 | 9.49 | 9.82 | 10.14 | 10.46 | 10.76 | 11.05 |
| 2 | 11.34 | 11.62 | 11.90 | 12.16 | 12.42 | 12.68 | 12.93 | 13.18 | 13.42 | 13.66 |
| 3 | 13.89 | 14.12 | 14.35 | 14.57 | 14.79 | 15.00 | 15.22 | 15.43 | 15.63 | 15.84 |
| 4 | 16.04 | 16.24 | 16.44 | 16.63 | 16.82 | 17.01 | 17.20 | 17.39 | 17.57 | 17.75 |
| 5 | 17.93 | 18.11 | 18.29 | 18.46 | 18.63 | 18.81 | 18.98 | 19.15 | 19.31 | 19.48 |
| 6 | 19.64 | 19.81 | 19.97 | 20.13 | 20.29 | 20.45 | 20.60 | 20.76 | 20.91 | 21.06 |
| 7 | 21.22 | 21.37 | 21.52 | 21.67 | 21.81 | 21.96 | 22.11 | 22.26 | 22.40 | 22.54 |
| 8 | 22.68 | 22.83 | 22.97 | 23.11 | 23.24 | 23.38 | 23.52 | 23.65 | 23.79 | 23.93 |
| 9 | 24.06 | 24.19 | 24.32 | 24.46 | 24.59 | 24.72 | 24.85 | 24.98 | 25.11 | 25.24 |
| 10 | 25.36 | | | | | | | | | |

# THE COLLECTION OF RAINFALL AND OTHER HYDROLOGICAL DATA ON THE SOIL CONSERVATION PROJECT

by

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When intelligent control of any phenomenon is attempted it is always necessary first of all to determine the factors influencing it. These factors are then studied and the direction and magnitude of their influence is determined. The control of a phenomenon may consist in retarding or accelerating its rate or it may aim to eliminate it entirely.

Soil erosion is a natural phenomenon the rate of which in the United States has been greatly accelerated by such unwise practices as deforestration, overgrazing, and faulty agricultural practices.

The task of the Soil Conservation Service is the retardation of the rate of soil erosion and the restoration of its geological norms, thus alleviating such grave consequences of accelerated erosion as depletion of valuable top soil from agricultural land, the destruction of large tracts of land by gullying, and the silting of expensive artificial reservoirs and irrigation canals and structures. The by-products of the work of the Soil Conservation Service should be the replenishing of ground water and the diminishing of flood peaks.

Soil erosion is an extremely complex phenomenon. The factors influencing it are themselves quite complex in nature and so closely interrelated that it is virtually impossible to segregate them and treat each of them independently of the others.

Sheet erosion is known to be a function of intensity of precipitation, but one cannot discuss the effect of this factor in any specific case without knowing a number of other factors such as the type of soil involved, the magnitude of the slope, the type and density of the vegetative cover, and a number of hydrological factors. Gully erosion is dependent on such characteristics of stream flow as rate of discharge, velocity, silt content, etc. But one cannot discuss the extent of gully erosion without knowing the texture and structure of the soil composing the banks and bed of the gully in question.

Neither is wind erosion determined by wind alone. It is obvious then that to effectively control soil erosion, due consideration must be given to a multitude of widely varied factors. This was well realized when the Soil Conservation Service was established and as a result we have in this service a technical personnel of widely varied training consisting of soil specialists, agronomists, foresters, and engineers. Considering the wide variety of training and experience represented by the fields mentioned above, it seems that we have the best combination possible. The Soil Conservation Service should be in a position to work out the best possible methods to be applied in a given instance since any branch of the service is expected to avail itself of the advice and information of all the other

branches where they may be needed. The instances in which such cooperation is not required in the work of the Soil Conservation Service, are rather rare.

The engineering branch when deciding on a type of terrace to be used on a given farm may have to consult the soils branch with regard to the type of soil and its properties; the agronomy branch with regard to the crops to be grown and the methods of cultivation; and the forestry branch with regard to the treatment to be given to the land overlying the terraced farm and with regard to the types of vegetation to be used in controlling the terrace outlets. Each of the branches named may in turn have to consult all or some of the other branches to furnish the best answer to the problem. There is one type of information which is always indispensable to all branches of the service when they try to give an answer to the problems arising in the every day work of the Soil Conservation, and this is the hydrological data for the locality involved.

It may be well to illustrate briefly some of the instances in which such information may be needed by the various branches of the Service.

When an engineer designs a terrace, culvert, spillway, check dam, interception ditch, etc., etc., he invariably faces the problem of determining the maximum rate of flow and the frequency of its occurrence. The determination of these all important unknowns involves the knowledge of such hydrological factors as intensity, duration, seasonal distribution, and frequency of occurrence of rainfall; rates of infiltration; time of concentration, and a number of other related factors. When the agronomist chooses a crop to be grown he must have such information as: length of growing season, the amount of available precipitation and its seasonal distribution, maximum and minimum temperatures, hours of sunshine and other factors. The forester and the range management men when dealing with ecological problems must know the annual precipitation and its distribution with elevation; they may also have to know the rates of transpiration of various species that they may recommend; they may need data on the maximum wind velocities, etc., etc. Even the soil man is vitally concerned with such data as evaporation from soils, total precipitation, rates of infiltration depth of the water table, or the rate of flow of water and velocity distributions in a gully when he attempts to determine the comparative resistance of different soils to erosion. Although sketchy, the above illustrations show clearly the importance of hydrological data to the individual branches of the service.

To the service as a whole, hydrological data are useful in many ways. The work of the Soil Conservation Service being demonstrative in character, it is essential that some means be available by which to show the effectiveness of the work as it progresses. This can be shown very effectively by determing the silt and water run-off from a given area before and after control measures have been applied. In a similar way the necessity of control and the benefits derived from it may be shown to skeptics. By the same means the relative value of different control measures employed can be determined. It is, of course, understood that all related meteorological and other factors are to be determined before conclusions are arrived at.

Gaging the water and silt run-off from land in the early stages of accelerated erosion together with analyses of the silt for organic matter are useful in sounding warning to farmers whose good top soil is being washed away without any visible effects on the land. It seems to the writer that this warning should be an important part of the activities of the Soil Conservation Service. Men's activities can be highly effective in accelerating erosion, but not quite as effective in restoring depleted top soil to its original value. A few inches of good rich top soil represents many years of slow work by nature through such slow process as decay of vegetative matter, bacterial activity, etc.

Soil erosion control is a new field and consequently there are a great many problems to which the answer is yet to be found. One such problem to be answered in connection with gully control, for instance, is whether the erosive power of a stream increases or decreases with an increase in its suspended silt load. Many of these problems are being studied by first rate investigators in hydraulic laboratories in this country and abroad. However, results of laboratory studies on such subjects as silt transportation and erosion are greatly in need of verification in the field. The nature of the work of the Soil Conservation Service and the wide geographic distribution of its projects make it the most logical agency to verify under actual natural conditions the results obtained in the laboratories. On the other hand there are many problems which are of interest to the Soil Conservation Service only. The laboratory and field investigation of such problems must be undertaken by the service if it is to carry out its work on a rational scientific basis. An example of such investigations are the experimental plot studies, part of which is the laboratory study of the various types of devisors used to measure run-off from the experimental plots. This study is being carried on by Mr. Cook, Hudraulic Engineer of the Soil Conservation Service, in the Bureau of Standards' hydraulic laboratory. On at least one of the Soil Conservation Service projects, the Gila, the object of the work is to reduce the silting of reservoirs and irrigation structures. There it is important to know whether gully erosion or sheet erosion contribute the greatest amount of silt. Such a problem can be solved only by determining the amount of material carried by the stream at appropriately located sections.

Reliable hydrological data needed for the solution of the above mentioned and kindred problems can be obtained by careful observation and skillful analysis of the data collected.

Some of the Soil Conservation Service projects are located in regions for which some hydrological information may be obtained from government and state agencies such as the United States Weather Bureau, the United States Geological Survey, the Army Engineers, State colleges, etc., etc. However, in most cases the data available were collected with objectives other than Soil erosion control in view, and therefore give only a partial answer to the problems confronting the Soil Conservation Service.

Director H. H. Bennett and Dr. Lowdermilk, Vice-Director, realized at the very start that soil erosion is largely a hydrological phenomenon and that the collection of hydrological data on the projects must be made an

important part of the work of the Soil Conservation Service. Arrangements were made for the collection and study of such hydrological factors as stream discharge (both water and silt) and ground water studies on the Soil Conservation Service projects. The first step in this direction was taken as far back as December 1933 when a memorandum signed by Director Bennett was written to the United States Geological Survey concerning stream gaging and the collection of rainfall intensity data on eight of the Soil Conservation Service projects. In February 1934 ground water studies by the United States Geological Survey were added to the stream gaging on the eight projects. At that time a memorandum was also sent out to all regional directors instructing them to undertake ground water studies. The regional directors of the various projects were well aware of the importance of this phase of the work and as a result some hydrological data are being collected on almost all of our projects. In some cases such as where plot studies are being conducted complete meteorological stations have been established.

The records of the Washington office show that by January 1, 1935, a total of 361 standard United States Weather Bureau rain gages, 64 recording rain gages, 39 water stage recorders, 1 barograph, 28 maxima and minima thermometers, 7 anemometers, and 8 psychrometers have been ordered for the various projects. The nature of the equipment listed above indicates that a considerable amount of hydrological information is being obtained.

These data will be of great value to the service and to other hydrological agencies, provided a standard and uniform procedure is followed in collecting them. A few examples will illustrate the absolute necessity of standardization and uniformity.

It has been found by the United States Weather Bureau that objects in the vicinity of a standard rain gage have a marked effect on the amount of precipitation caught by the gage. A. F. Myer, in his book on hydrology, states that no objects near a gage should be within a distance equal or less than their height. It is known that the amount of rainfall caught by a rain gage varies with the elevation of the gage above the surface of the ground as much as 40% in 85 feet.

Robert E. Horton has shown that an unshielded snow gage collected .43" out of a total of 1.41" during a snowstorm.

To get comparable evaporation data it is necessary to follow the standard procedure employed with a given type of pan. It would not do, for instance, to employ a United States Weather Bureau class A land pan and perch an anemometer on an 18 foot tower when it should be 6" above the pan.

The United States Weather Bureau maintains 6000 cooperative stations from which daily rainfall and temperature data are obtained. Each of these stations necessarily covers a wide territory. To assume that the rainfall is uniform over such wide ranges would be rather naive, at least in some parts of the United States.

Too often erroneous conclusions have been drawn based on rainfall data from such widely spaced stations. It is therefore imperative that the rain gages on the Soil Conservation Service areas be well distributed so that isohyetal maps showing the actual distribution of rainfall from a given storm can be drawn. Hours could be consumed in citing additional proof for the necessity of a standard and uniform procedure in collecting and recording hydrological data.

The importance of the records and the necessity of standardization has been fully recognized by the Vice-Director, Dr. Lowdermilk, and he assigned the task of standardization and coordination of the collecting and recording of the hydrological data collected on the Soil Conservation Service projects to the writer. An all inclusive form for recording meteorological data has been devised which is suggestive to observers. A similar form is being devised for the gaging stations and for the ground water studies. Standard procedure to be followed in the installation of hydrological stations and in collecting the data will be established with due consideration given to the procedure employed by other hydrological agencies.

A memorandum has been sent out to all regional directors requesting the basic information about the established stations. This information will be carefully studied and the forms and procedures revised so as to fit those used by the various projects as much as possible. The writer will visit the projects in the course of his duties and will become familiar with the specific conditions of the individual area; he will assist the local men in their problems, and learn as much as possible from their experience. This procedure will enable an intelligent analysis of the data obtained.

Through the medium of memoranda and the Soil Conservation Service official publication "The Land" the writer intends to discuss the various hydrological phases of the work of the Soil Conservation Service. The writer will endeavor to answer all inquiries and to supply all information concerning the hydrological phases of the work on the various projects. Close connections will be established with all hydrological agencies carrying on work in the vicinity of the Soil Conservation Service project areas, and use will be made of their data to supplement the data of the Soil Conservation Service wherever possible.

It is the writer's hope that this paper will make the personnel of the projects hydrology conscious, and that he will be given full-hearted cooperation in his work in the future.

# PRELIMINARY RESULTS ON TERRACING COLLECTED AT THE SOIL CONSERVATION EXPERIMENT STATIONS

by

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The control of soil erosion consists essentially of controlling the run-off water. If all of the rain water were absorbed by the ground upon which it falls, there would be no water erosion. It is obvious therefore that in order to prevent or reduce erosive action to a minimum, the soil must receive treatment that results in the admission and storage of large quantities of the rain water; and methods must be employed to reduce the velocity which tends to increase the amount of water absorbed by the soil and to diminish the erosive and transporting power of the run-off water.

Since the storage capacity of a soil depends upon its porosity, any treatment that results in an increased porosity of the soil will reduce erosion materially. This porous condition is usually obtained directly by deep plowing and by plowing under manure, stubble, stalks and cover crops. Methods of subsurface drainage, which lower the ground water level, improve the porous structure of the soil, thereby increasing its capacity to absorb surface water.

The treatment of cover such as seeding land to pasture, growing timber and planting cover crops in winter, promotes absorption and reduces the velocity. Other methods which promote absorption by retarding the flow of the water and which makes possible the removal of the water from the field at a low non-eroding velocity are contour farming, strip cropping, diversion ditching, and terracing.

The degree of erosion control afforded by the methods enumerated above varies greatly. Also one method may be preferable to another for a particular set of conditions relating to rainfall, soil and topography from the standpoint of low cost and effectiveness. In most instances, several of the methods may be and should be combined where the cost is not exorbitant and where any of them do not interfere too seriously with practical farm management and operations. From this it is seen that the proper study of a particular erosion control problem depends upon a knowledge of the cost, effectiveness and practicality of the various erosion control measures and its proper solution depends in turn upon a carefully balanced relation of these three factors.

The problems involved in most methods of erosion control require a knowledge of rainfall, run-off, percolation and an intimate knowledge of hydraulics as it pertains to the flow of water in drainage channels, such as terrace channels and outlet ditches, and also to the flow over the ground surface as modified by various roughness conditions of the ground surface and vegetative cover. The engineer receives special training and education in the foregoing subjects which particularly fit him for dealing with erosion control practices. In addition, a knowledge of crops and other vegetation best adapted to any particular locality together with

information relating to crop methods and practices; a knowledge of tree varieties and their adaptablilty to any particular locality; and a knowledge of the physical properties and fertility of different types of soil, are required.

With this information the best methods of controlling the run-off water in any particular locality can be formulated and the part that the different methods of erosion control involving the use of vegetation, timber, farm practices and terraces should play in a comprehensive and harmonious plan designed to control most effectively the run-off water and thereby soil erosion can be determined.

The technique of soil erosion control by terracing is founded upon two basically engineering subjects - drainage and the dynamics of erosion. Drainage involves a knowledge of the fundamental principles underlying rainfall, run-off and hydraulics; and erosion, a knowledge of mechanics and hydraulics in their relation to the dynamics of flowing water. The practice of terracing and gully control by dams requires an intimate knowledge of two other engineering subjects, surveying and construction.

Erosion of soil by water depends upon the velocity of the water which in turn depends upon the slope of the land, the condition of the ground surface from the standpoint of roughness and cover, and upon the volume of water.

Erosion is therefore more active on steep slopes because the run-off water attains a higher velocity than on gentle slopes and can remove more soil. This holds true particularly after the water begins to accumulate in small rivulets or channels. Roughness of ground surface increases the frictional resistance to flow which reduces the velocity and thereby the erosive power of the water. Also a cover of vegetation tends to reduce the velocity in somewhat the same way which results in less erosion.

Less erosion occurs when water is scattered in a thin sheet over a wide area than where the same volume is confined to a narrow strip or channel because the velocity is much less for the thin sheet due to the greater frictional resistance to flow as has been determined by hydraulic experiments. Water in flowing down a land slope travels for a short distance in a thin sheet depending upon the smoothness of the surface. This sheet is soon broken up into tiny streams which tend to increase in size as they travel down a slope. As these streams increase in size, the volume of water and the velocity increases resulting in an increase power to erode.

In order to prevent the development in the size of such streams of water, which as they proceed down the slope gain increasing momentum and power to tear away the soil and produce gullies of increasing size, it is necessary to intercept the water at regular intervals on the slope. Controlling this run-off water so as to reduce its erosive action is a problem in drainage which consists of providing for the removal of the run-off from land slopes resulting from rains of high intensities and this must be done in the most economical manner, that is, the cost of the method employed should be the lowest consistent with adequate and satisfactory measures of erosion control. Unduly high costs or inadequate measures of erosion gen-

erally result with unscientific guesses are relied upon instead of fundamentally sound engineering experimental data. One of the most effective methods of controlling run-off water is properly planned hillside drainage which consists of the construction of drainage channels on hillsides located in such a manner that they will collect the run-off water and conduct it to a suitable outlet before it attains sufficient velocity to cause appreciable erosion of the soil. This method of hillside drainage is generally known as terracing.

The drainage channels which intercept the run-off water and prevent its rapid flow down the slope are formed by throwing up broad ridges of soil called terraces. In terracing land the first terraces are located near enough to the top of the hillside to collect the run-off water before it attains sufficient velocity to cause appreciable erosion of the soil, and the remaining terraces below are spaced at suitable intervals to serve the same purpose. By giving fall to the drainage channel of the terrace, the water that collects in it is conducted to an outlet channel located in a natural watercourse or along the boundary of the field. From the foregoing it is evident that terraces should be spaced close enough together to prevent the concentration of water and thereby appreciable erosion on the land slope between the terraces. In the spacing of terraces, however, another important factor must be considered and that is the ability of the terrace channel to carry away the run-off water which is delivered to it from the land slope between the terraces for rains of high intensity. The amount and rate of movement of water that runs off between the terraces depends upon the nature of the soil, the vegetative cover, the slope of the land, the amount and intensity of the rainfall and the shape, length and size of the drainage area. The results of many carefully conducted run-off experiments, collected over a long period of years by reputable engineers, include a study of the effects of the foregoing factors, and long-time records relating to the amounts and intensities of rainfall as collected by the Weather Bureau furnish information indispensible to the correct computation of run-off from the area drained by terraces. With this information the engineer finds it possible to compute with accuracy the rate and amount of water delivered to the terrace channel.

Experimental results obtained during 1933 at the Guthrie soil erosion station confirm the results for 1931 which showed that soil losses increased for increase in terrace spacing when the land was planted to a clean cultivated crop such as corn. The results for the two-year period at Guthrie show that the average annual soil losses in tons per acre were 2.65, 4.15 and 4.97 tons per acre for vertical spacings of 2, 3 1/2, and 5 feet respectively on a land slope of about 5 1/2 percent. Similar results were obtained for the Tyler Station, the average annual soil losses for the experiment being 3.68, 5.47, and 5.74 tons for terraces with vertical spacings of 3, 4, and 5 feet on a land slope of about 7 percent during a three-year period when the land was planted each year to clean cultivated crops, cotton in 1931 and 1933, and corn in 1932.

Results at Guthrie for the year 1932 when the land was in oats showed very little difference for the different spacings. In fact the greater losses occurred for the smaller spacing but the difference was not large enough nor the record long enough to warrant any conclusions.

It appears that this difference in results for clean cultivated and grain crops is due to the development of small gullies on the wider terrace spacings when in cultivated crop; and the absence of such gullies when in grain crop. Wider spacings permit a greater concentration of the run-off water particularly on non-uniform and irregular slopes and gullying increases with the distance travelled by the concentrated water. This results in a greater accumulation of soil in the terrace channel at points of concentration for the wider spacings. This greater deposit of soil in the channel of the terraces with wider spacing results in greater soil losses for wider spacings particularly for long terraces with large drainage areas since the volume of water removed by such terraces especially near the outlet end is sufficient to carry away a large part of the soil deposited in the terrace channel. Since the velocity and thereby erosive power of the water increases with the grade of the terrace, no doubt the greater the grade of the terrace the greater will be the increase in soil losses with increase in terrace spacing.

The ability of a terrace channel to carry away the run-off water delivered to it depends upon its shape, its fall, its cross-sectional area, and the frictional resistance to flow. The discharge capacity of the channel is computed by the formula $Q = CA\sqrt{RS}$ where

Q = the discharge in cubic feet per second
C = a coefficient representing the frictional resistance to flow
A = the cross-sectional area in square feet
R = the hydraulic radius depending upon the size and shape of the channel
S = the fall of the bottom of the channel

The results of extensive field and laboratory experiments enable the engineer to determine all of the above factors in computing the discharge capacity of a terrace channel. This is particularly important since terrace failures due to exceeding the discharge capacity of the channel and resulting in the water's overtopping and breaking the terrace are of common occurrence where their design has not been based upon sound engineering methods and principles.

A terrace channel must not only be able to remove the water from the drainage area between the terraces but must accomplish this without excessive erosion in the terrace channel. In other words, it must conduct the water to the terrace outlet at a low, non-eroding velocity. Both the fall and the shape of the channel can be controlled so as to produce the desired velocity for any particular soil.

A broad, shallow channel will have a lower velocity than a deep, narrow channel. To illustrate, the two channels shown in Figure 1 are capable of removing the same quantity of water from the drainage area in the same time but the broad, flat channel removes it at a comparatively low velocity of 1.44 feet per second and the narrow, deep channel at a velocity of 2.29 feet per second, a velocity sufficient to cause erosion.

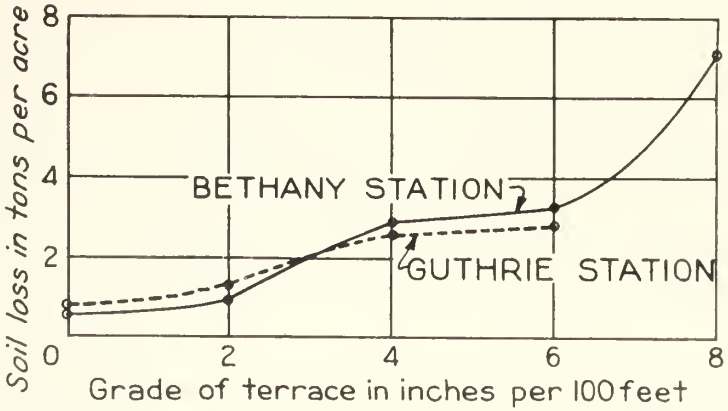


Fig. 1 Curves showing soil losses from terrace with different grades for year 1932 at Bethany and 1933 at Guthrie.

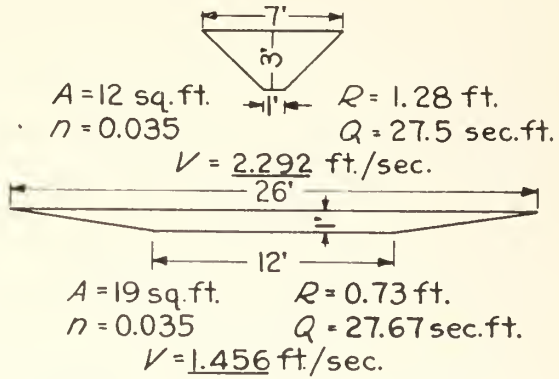


Fig. 2 Comparison of velocities of deep and shallow channels. For fall of 3 inches per 100 ft.

TABLE NO. 1

Run-off and Soil Losses From Terraced and Unterraced Land at Several Soil Erosion Experiment Stations

| Experiment Station | No. of Terrace or Watershed | Period Years | Annual Soil Losses In Tons Per Acre | | | Annual Run-Off In Percent of Rainfall | | Average Slope Of Land In Feet Per 100 Feet | | Crops | Annual Rain-Fall Inches |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Terraced | Unterraced | Terraced In Percent of Unterraced | Terraced | Unterraced | Terraced | Unterraced | | |
| Guthrie | Watershed 13 Terraced 6-C | 1931 | 1.25 | 43.90 | 2.8 | 10.7 | 22.7 | 5.5 | 5.1 | Young Oats* Mature Cowpeas Fallow | 27.3 |
| Guthrie | Watershed 13 Terraced 6-E | 1932 | 4.06 | 88.06 | 4.6 | 23.3 | 30.8 | 5.5 | 5.1 | Fallow Cotton | 36.2 |
| Guthrie | Watershed 13 Terrace 6-E | 1933 | 1.33 | 60.39 | 2.2 | 21.9 | 14.1 | 4.6 | 5.1 | Winter Wheat Winter Wheat Cotton | 30.4 |
| | Average Annual | | 2.21 | 64.12 | 3.4 | 18.6 | 22.5 | | | Later Grass in Cotton | 31.3 |
| Tyler | Watershed 4 Terrace 7-C Terr. Culti | 1933 | 4.55 | 41.03** | 11.1 | 14.0 | 16.5 | 5.8 | 7.5 | Cotton Followed by Fall Oats | 45.7 |
| La Crosse | Watershed Ter. 2C to 4C | 1933 | 2.23 | 31.70 | 7.0 | 4.9 | 8.9 | 12.7 | 13.1 | Barley Followed by Clover | 26.8 |
| Bethany | Watershed D3 Terrace 2-H | 1933 | 3.19 | 27.09 | 11.8 | 18.7 | 19.2 | 8.3 | 6.7 | Corn Followed By Sweet Clover | 31.7 |
| Pullman | Watershed 4 Terraces 5, 7 and 17 | 1932 | 2.85 | 22.53 | 12.6 | 10.0 | 24.8 | About 20 | About 20 | Winter Wheat Following peas Winter Wheat | 24.4 |
| Pullman | Watershed 4 Terraces 5, 7 and 17 | 1933 | 3.53 | 11.26 | 31.3 | 12.4 | 37.3 | About 20 | About 20 | Winter Sheat Stubble Winter Wheat Stubble | 28.8 |
| Pullman | Watershed 4 Terraces 5, 7 and 17 | | | | | | | | | Fallow Winter Wheat | |
| | Average | Annual | 3.19 | 16.90 | 22.0 | 11.2 | 31.0 | | | | 26.6 |

* Crops are given for terraced area. Crops for unterraced area are Winter rye, mature cowpeas and winter wheat

** Gullies and watercourse protected by brush dams.

The deep channel has a cross-sectional area of only 12 square feet as compared with a cross-sectional area of 19 square feet for the shallower channel. The shape of the channel alone, due largely to the fact that the perimeter of the cross-section with which the water comes in frictional contact is only 9.4 feet for the deep channel and 26.1 feet for the shallow channel, is responsible for the small deep channel carrying as much water as the large shallow channel.

From the foregoing it has been seen that the control of erosion in a terrace channel can be accomplished, to a limited extent, by the shape of the channel. This alone would, of course, not be effective if the fall of the channel were not limited.

Excellent results have been obtained at both the Guthrie and Bethany Soil Conservation Stations on the effect of terrace grade upon soil losses for several different grades. In Figure 2 are shown graphically the soil losses during one year for terraces with different grades when the terraces at both stations were cropped to corn. It is seen from the table that the losses for a 6-inch grade at Bethany are nearly 5 times as much as for a terrace with a level grade and about 3 times as great as for a terrace with a 2-inch grade while at Guthrie it is nearly 4 times and over 2 as great respectively. In Table No. 1 are given the soil losses for terraces with different grades at all of the stations where satisfactory data has been obtained.

Appreciable scouring in the terrace channels with 6-inch and 8-inch grades was apparent at both Guthrie and Bethany. At Guthrie, the yields of cotton and corn were less for the level terrace and for the terrace with the 6-inch grade. The smaller yield in the level terrace channel was attributed to partial drowning or excess moisture in the channel and in the channel with 6-inch grade to the washing out of some of the small plants due to the high velocity of the water. From these results it appears that sufficient grade should be given a terrace to provide satisfactory drainage of the terrace channel and yet not so much as to cause appreciable erosion.

It is seen from the table that level terraces with open ends are more effective in conserving both the soil and water losses at Guthrie and Bethany, the soil losses from a level terrace being about 50 percent and 25 percent respectively for the two stations, of that from a terrace with a uniform grade of 4 inches per 100 feet, and the water losses from a level terrace being about 80 percent and about 60 percent respectively of that from the 4-inch grade terrace. The slight damage that is done to crops in level terrace channels is partly offset by the effectivemess of this terrace in conserving more of the soil and water particularly for open permeable soils. At Tyler, Texas, level terraces on gentle slopes and sandy soils have given very satisfactory service where carefully built and maintained. One of the important things to remember about level terraces is that they require more care in maintenance and construction than a graded terrace. One neglected low place in a level terrace will result in the water pouring over, coming from both directions along the terrace. A similar low place in a graded terrace particularly near the upper part of its length where the channel is never filled may result in no overtopping since the cross section of the channel below the top of the low place is often large enough to carry the moving water along the channel and by the low place in the terrace embankment.

A uniform graded terrace at Bethany having a grade of 4 inches per 100 feet gave a soil loss about 37 percent greater and a water loss about 33 percent greater than a variable graded terrace having a grade of 1 to 4 inches per 100 feet during a two year period. Both terraces were 1,200 feet long, had vertical spacings of 5 feet and were on the same land slopes. Also for the three largest storms that occurred during the year 1933 the average of the maximum rates of run-off during the storms for the uniform graded terrace were slightly over twice as great as for the variable grade terrace. Similar results were obtained on the Station at Tyler, Texas, where the soil loss was about 15 percent greater and the water loss 27 percent greater for a uniform than for a variable graded terrace. Also the rate of run-off from one of the largest storms was about 40 percent greater for the uniform graded terrace.

From these results it is apparent that the variable graded terrace is not only more efficient in conserving both soil and water but does not require as great a height as the uniform graded terrace due to the smaller maximum rate of run-off or maximum discharge during storms. The flatter grades near the upper end of a variable graded terrace tend to store or hold back the upper water until the water below has a chance to flow off. This prevents the concentration or piling up of the run-off water near the lower or outlet end of the terrace so that a lower terrace embankment can be used for a variable graded terrace under the same field and rainfall conditions without the possibility of overtopping. These advantages of the variable graded terrace over the uniform graded far outweigh a minor objection, namely, that the variable graded terrace is slightly more difficult to lay out in the field than the uniform graded.

These results show conclusively that soil losses from a terraced field increase appreciably with the grade of the terrace and in order to reduce the losses it is necessary to lower the erosive and silt carrying capacity of a terrace channel by limiting the grade and thereby the velocity in the channel. The minimum grade should be used that will be effective in removing the run-off water from the contributing drainage area between the terraces which increases with the length and the distance between the terraces.

The results of a two-year experiment at the Tyler Station continue to show that soil losses increase with the length of the terrace. The average annual soil loss for a terrace 1,700 feet long was about 30 percent greater than for a terrace 700 feet long. On the other hand, the longer terrace conserves more of the rainfall. The percent of rainfall running off was 22.8 percent for the short terrace and only 16.7 percent for the long terrace. Similar results were obtained for long and short terraces on the Station at Pullman, Washington, where during a two-year period the soil loss for a terrace 2,300 feet long was over twice as large as for a terrace 800 feet long and the percent of the rainfall running off for the short terrace was over double that for the long terrace.

From the foregoing discussion it can readily be seen that considerable ingenuity must be exercised in planning terrace embankments on different land slopes so that the cross-sectional area of the channel will be sufficient to take care of the run-off water; so that appreciable erosion will not occur in the terrace channel; and so that the shape of the terrace embankment will

not be such as to interfere with the easy operation of machinery in farming the embankments. The type of an embankment will necessarily not be the same on a steep slope of 15 percent as on a comparatively flat slope of only 3 percent in order to meet satisfactorily the foregoing requirements.

The height of a terrace determines largely the cross-sectional area of the waterway for any particular slope. The higher the terrace, however, the more interference with the operation of farm machinery. If the height of a terrace is kept low in order to meet farm machinery requirements, this may necessitate reducing the drainage area by a closer spacing of the terraces or by increasing the grade of the channel in order to prevent the run-off water from overtopping the low terrace embankment. Thus it is seen that the interdependence of all factors governing the design of a terrace is such that if a change in any one is made, readjustment of the remaining factors becomes imperative in order to restore the proper balanced relation of the various factors.

In general it can be said that there is considerable agreement among the results obtained at the various stations that terraces should be originally constructed 18 inches high with the expectation that they will settle to a height of not less than 15 inches from the standpoint of satisfactory machinery operation and necessary water capacity of the terrace channel. In some recommendations, however, the height is reduced for the steeper land slope and this would seem advisable since it is difficult to build and also to operate machinery on a high terrace built on a steep slope. Considerably more study will be required to work out the most satisfactory heights that should be used for different land slopes, types of soil and machinery at the different stations. No doubt final recommendations will vary considerably depending upon these governing factors.

The proper width for a terrace is even more difficult to determine for all governing conditions than the height since the width is a rather indeterminate dimension. It is usually taken as the distance from the last cut made on the upper side of the terrace in construction to the last cut on the lower side of the terrace or to the edge of the fill on the lower side when the terrace is all built from the upper side. Not only the width but the degree of the side slope given to the terrace embankment has a decided effect upon the ease of operating farm machinery across the terrace, a terrace embankment with comparatively flat side slopes being better for the easy operation of machinery. It seems to be the consensus of opinion judging from the results thus far obtained that the width of terrace should decrease with increase in slope in order to obtain an economically-built terrace embankment with sufficient channel capacity for the run-off water. On the station at Bethany, Missouri, where two-row equipment is used parallel to the terraces, terraces with width varying from 22 feet on a 3 percent slope to 16 feet on a 20 percent slope have been found to be quite satisfactory. Where single row equipment is used it is estimated that the widths could be two-thirds of those given above.

On the Hays, Kansas Station where large combines are used in harvesting wheat across terraces, terraces 30 feet wide and 12 to 20 inches high on moderate slopes of less than 5 percent have been found to be satisfactory

but on steeper slopes it was found advisable to operate the combines parallel to the terraces of these dimensions. Combines on the Pullman, Washington Station have been operated satisfactorily parallel to terraces having widths of 24 to 27 feet and heights of 12 to 15 inches on land slopes of 14 to 29 percent.

On both the Tyler and Bethany stations small terraces of about half the width and height recommended in the foregoing were built to obtain information on the practicability of using such terraces in order to reduce the cost of construction. Serious damage to these terraces resulted from overtopping and breaking during the first moderately heavy rain which indicated quite conclusively that such small terraces could not be used where the land is cultivated.

Planning a terrace system for any particular field and actually locating the terrace lines and terrace outlet channels is an engineering job requiring a knowledge of drainage and surveying together with practical experience in such work. A preliminary reconnaissance of a field is necessary to secure the most satisfactory and economical location for terraces and terrace outlet ditches. Ill-considered and hastily prepared plans usually result in unsatisfactory terraces. The proper diversion of water from outside areas of pasture, timber or other unterraced land lying above the terraced field and the choice of natural or artificial outlets for the disposal of the terrace water are purely drainage problems. The actual laying out of the terrace lines in the field and the field location of the terrace outlets are surveying problems and unless properly and carefully done, the terracing system will never function successfully. For instance a mistake in laying out the grade of the terrace resulting in a low place in the top of the terrace would be the cause of the run-off water overtopping the terrace embankments with the possibility of all terraces being washed out below and the development of a bad gully down the field slope. A mistake made in giving a terrace too much grade would result in undue washing in the terrace channel and the excessive loss of good soil from the field.

The construction of terraces involves a knowledge of soils and machinery together with experience in the best methods of operating the machinery so as to move the soil in the most economical manner. In constructing terraces, attention should be given to the type and condition of soil, in the same manner as is done in constructing highways, ditches, railway embankments, and other forms of earthwork requiring the services of an engineer. While terraces can be built satisfactorily on any soil, some study should be made to determine the best methods, the most suitable machinery and the best shape of cross-section for the embankment for a particular soil. For instance, the heavy clay blackland soils in central Texas are much more difficult to work than the sandy clay soils in the Red Plains region of Oklahoma, and with certain types of small terracing machines nearly twice as much work is required to build terraces in the former region, while with larger machinery there is very little difference in the cost. Different methods and more work is required to build a terrace when the soil is extremely dry than when in the best tillage condition. Some soils tend to melt away when built into terrace embankments. Terraces in such soils require larger terrace embankments with flatter slopes and more attention to proper maintenance.

Two general methods have been used in building terraces, one of which consists of moving all the dirt from the upper side and the other of moving the dirt from both sides, either in equal or unequal amounts. The second method does not require moving the dirt as far as the first and does not necessitate the reversing of the terracing implement where an equal number of trips are made on both sides. Moving all of the dirt from the upper side has the advantage of making a larger channel above the terrace for the run-off water. It is also easier to move the soil down than up the slope. Results thus far obtained seem to indicate that it is cheaper to build terraces from both sides equally on slopes up to about 4 percent and on greater slopes it is found cheaper to increase the amount of dirt moved from the upper side until all but one trip is made on the upper side on slopes of 10 percent or greater. The one trip on the lower side tends to prevent material from rolling too far down the slope.

On loessial soil, as on the Clarinda, Iowa, Station, it has been found preferable to build the terraces by moving the soil from both sides since it was found impossible to obtain a smooth, regular uniform slope on the lower side of the terrace when all of the soil was moved from the upper side.

Considerable experimenting has been done with different machines to determine the best method of moving the dirt into the terrace embankment so as not to move the same dirt two or more times and so that the tractor can be operated on firm ground as much as possible. It was found that the order and width of making cuts or in moving the dirt varied for the same terracing machine depending upon whether it was operated by teams, wheel or crawler tractors. Different types of tractor wheels or widths of tread also affected the best method to be employed in cutting and moving the earth. Considerable more experimental work would need be done before definite methods could be determined upon for even the most commonly used combinations of terracing machinery and power.

The control of erosion in terrace outlet ditches or gullies is a much more difficult problem than in terrace channels. The same engineering principles apply but the general practice of an outlet ditch carrying the water to the foot of the slope along a natural depression or through an artificial channel often located directly down a slope along a road or a fence results in a large fall in the outlet ditch. The velocity in the channel may be reduced somewhat by using a ditch with a broad, shallow cross-section but not sufficient to prevent erosion. Additional protection against erosion is required by either further reducing the velocity or by protecting the channel with a short growth of grass which will not reduce too much the water carrying capacity of the ditch. Even on moderate slopes it has been found advisable and necessary in most cases to cause an equal distribution of the water across the bottom of the channel by means of planks buried on edge in the ground at close intervals across the channel and with their upper edges about flush with the bottom of the channel. If this is not done there is a tendency for the water to concentrate and cause serious erosion. Also the plank holds the grass in place and checks any small gully erosion that may start between the planks.

Untreated and creosoted plank have been used in building drop check dams which are semi-permanent and have proved very satisfactory on most of the stations. However, the lumber in these dams is subject to warping which often results in serious leaks and failure of the structure.

A great variety of temporary checks of perishable material used in connection with vegetation have been built. These are usually installed in terrace channels with uniform bottom slopes and no part of the check is left projecting above the bottom of the channel. Plank checks have been used very successfully at the Bethany, Missouri, Station in this method of protecting outlet channels where a satisfactory growth of a grass mixture, principally blue grass, was established in one season. Logs are sometimes used in place of planks. Checks serving the same purpose have been built by filling a trench 2 feet deep and 18 inches wide with loose rock and setting a strip of sod about 18 inches wide above and below the upper and lower edges of the rock. Another method is to hold this rock in place by means of woven wire. Brush has been used successfully in building these checks and is satisfactory on moderate slopes. Any material used in building construction or available on the farm may be made use of in building checks but observations show that it is important that the top surface of the material must not extend above the bottom of the ditch and the surface should be exactly level so as to spread the water over the entire bottom of the channel which prevents concentration and thereby gullying in the bottom of the channel.

Natural channels used as terrace outlet ditches often are located on moderate slopes and have a good growth of vegetation sufficient to prevent erosion. However, where the channel is on a fairly steep grade or is not fully protected by vegetation, additional protection is needed and this can be supplied by means of check dams, the top of which to be set preferably below the bottom of the ditch and follow the curved perimeter of the channel. This is permissible in such channels where the bottom is sufficiently protected by a fairly high growth of vegetation which prevents gullying due to the concentration of water. Also the usually excessive cross-section area of such channels permits the growth of higher vegetation than could be permitted in artificially built channels with limited cross-section.

Ditches with large drainage areas or on steep slopes cannot be very effectively controlled by the foregoing method. Also it is not always possible, in all locations, to build a broad, shallow ditch or in some sections of the country to secure a satisfactory sod in the ditches. Under these circumstances control of the ditch or gully is usually accompanied by means of check dams built of a variety of temporary or permanent material and so spaced in the ditch that the crest of one dam is about on the same elevation as the foot of the next dam above. The object of spacing the dams in this manner is to reduce the fall of the ditch between the dams, and thereby the velocity and erosive power of the water. The dams are constructed with an apron below to prevent erosive action of the water after dropping over the dam at an appreciable velocity. The proper design and construction of these dams require an intimate engineering knowledge of structures, strength of materials, and hudraulics together with practical experience in order to insure their stability under the severe conditions of flow to which they are subjected. Numerous failures of dams built by farmers or people lacking engineering training have resulted from excessive hydraulic pressure that was not taken into consideration in the design of the structures.

It has been found that most methods of erosion control in terrace outlet channels and at the ends of terraces are rather expensive and that a special effort should be made to reduce the cost without reducing the effectiveness. Very substantial and effective drop check dams can be built with concrete, masonry rock, brick, hollow building tile and other permanent material, and an effort is being made to use these materials and still keep the cost down. Loose rock held in place by woven wire has been found to be fairly cheap. Large loose rock properly placed with Bermuda grass growing between the rocks seems to be quite effective for limited drainage areas. Formless concrete dams of limited height with very little reinforcement seem to offer a possibility of a comparatively cheap structure of a permanent nature. Also check dams built of small concrete blocks made in the field by the farmer have been constructed at a comparatively low cost.

It has been found from observation of a large number of fields that the effectiveness of pasture or wood lands in acting as a place for the disposition of terrace water depends upon the following factors: Condition of surface cover of the woods or pasture from the standpoint of resisting erosion, slope of the woods or pasture land, volume of water entering woods or pasture in one stream, and possibility of a gully eating back at the foot of the slope in pasture or timber where water enters a drainage channel.

In some sections of the country it is often difficult to establish a growth of close-growing grasses that will resist erosion satisfactorily, there often being bare spots which leave an opening for erosion to get started and permit the development of a gully. Even in sections where a luxuriant growth of thick grass is easily established, it is not always effective against erosion if the grass is over-pastured, since this nearly always results in the development of bare spots, particularly during dry years which are susceptible to erosion. Pastures with thick, well matted grasses serve better in terrace outlets than wooded land since if water is permitted to concentrate on wooded land it will soon wash off the vegetable cover of leaves and other organic material and then the earth will be directly subjected to the erosive action of the water. The binding power of roots does not help sufficiently to resist the action of the water, as is quite often evidenced by the exposure of nearly the entire root systems of trees due to erosion. Much better results are obtained, when using pasture or wooded land as terrace outlets, if an effort is made to spread the water into a thin sheet over the surface of the ground. This is particularly true of wooded land. In some instances this has been accomplished by means of a series of stakes set just below the outlet of the terrace which tends to spread the water over a wide area. Another method used at the LaCrosse Station is to extend the terrace embankment into the wooded or pasture land and provide several openings in the embankment so that part of the water will discharge at these openings and only part of the water will reach the end of the terrace.

The possibility of erosion occurring on pastures or wooded land used as terrace outlets increases as the slope of the land increases. On very steep slopes a much better surface cover and a more complete spreading of the water is required to prevent erosion than on moderate slopes. Also the same principle applies to large volumes of water discharged from large drainage areas since the velocity and erosive power of water increases with the volume.

Another condition which must receive careful attention is what becomes of the water after it reaches the foot of the pasture or wooded slope. If, as was found in two widely separated locations, a pasture area in Wisconsin and a timber area in Alabama, it drops over into a deep gully, then a lateral gully will develop and will eat its way up the slope regardless of the protection afforded by pasture or timber.

In general it is believed that a great deal of caution should be used in recommending pasture or wooded land for terrace outlets and on account of the several factors influencing erosive conditions they should not be recommended indiscriminately.